GUSTAVO NEMI CASTRO

Improving production planning: a case study in a food company with seasonal demand

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To all my Family
for the caring support
throughout
my academic life

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Gustavo Nemi Castro

RESUMO

O presente projeto foi realizado em uma empresa brasileira do setor alimentício com a finalidade de aprimorar o processo de planejamento da produção das suas categorias de produtos com alta sazonalidade. Através do uso de ferramentas de mapeamento de processo e do *framework* da hierarquia de planejamento da produção, dois pontos principais de melhoria foram identificados pelo projeto. O primeiro deles se relaciona com o processo informal de decisão durante o planejamento de capacidade da empresa, o qual ela realiza anualmente ao rebalancear suas linhas de produção. Em relação a esse ponto, foi desenvolvido um modelo de simulação que reproduz o processo produtivo da empresa, e a auxilia no rebalanceamento de suas linhas ao permitir que ela preveja o desempenho operacional decorrente de investimentos em novos equipamentos. O segundo ponto de melhoria está relacionado com o planejamento agregado da produção. A fim de incitar a empresa a planejar os seus níveis mensais de produção, de estoque e de mão-de-obra de forma agregada e considerando os custos produtivos pertinentes, foi desenvolvido um modelo de planejamento da produção baseado em programação linear inteira mista. O uso efetivo dos modelos desenvolvidos contribui para que a empresa esteja apta a tomar decisões mais robustas no planejamento da sua capacidade produtiva e da sua produção.

Palavras chave: Planejamento da Produção. Programação Matemática. Sazonalidade. Simulação de Sistemas.

ABSTRACT

This project was motivated by the request of a Brazilian food company, which recognized the importance of improving the production planning process of its products with high seasonal demand. With the use of process-mapping tools and the hierarchical production planning framework, two main points of improvement were identified in the company with respect to its capacity planning and its aggregate production planning. The project addressed these points by developing two distinct decision-support models: a line-balancing model, based on simulation, and a production-planning model, based on Mixed-Integer Linear Programming. The line-balancing model reproduces the company's existing production lines, and supports their rebalancing by allowing the company to predict their future operational performance derived from investments in new equipment. The production-planning model determines the monthly production, inventory and workforce levels that fulfill the company's demand while maximizing its gross margin. Thus, the production-planning model provides the company a systematic way to work with aggregate data and production costs in its production planning. With effective use of these models, the company is able to make well-grounded decisions with respect to its capacity and aggregate production planning.

Keywords: Production Planning. Mathematical Programming. Seasonality. System Simulation.

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LIST OF ABBREVIATIONS AND ACRONYMS

APP	Aggregate Production Planning
BOM	Bill of Materials
BPMN	Business Process Model and Notation
CRP	Capacity Requirements Planning
DES	Discrete Event Simulation
DMAIC	Define, Measure, Analyze, Improve and Control
EDD	Earliest Due Date
HPP	Hierarchical Production Planning
HR	Human Resources
IDEF0	Integrated Definition
LP	Linear Programming
MILP	Mixed-Integer Linear Programming
MPS	Master Production Scheduling
MRP	Material Requirements Planning
MTS	Make-To-Stock
PP&C	Production Planning & Control
RCCP	Rough Cut Capacity Planning
SFC	Shop Floor Control
SIPOC	Supplier-Input-Process-Output-Customer
SP	Stochastic Programming
SKU	Stock Keeping Unit
SPT	Shortest Process Time
WIP	Work-In-Progress

SUMMARY

1 INTRODUCTION

This report describes the development and the results of a project aimed at improving the production planning process of a food company – **Company A** (the firm has preferred to remain unidentified for competitive reasons).

The company's main points of improvement have been identified with the use of process-mapping tools and the hierarchical production planning framework. After prioritizing the identified points, this project has selected and focused on two issues: the capacity planning and the aggregate production planning of Easter eggs and *panettones*.

With the intent to provide an overview about this work, this chapter presents its context, its motivation, its objectives, and its relevance for the company.

1.1 Context

Company A began its operations in 1968 as a bakery, and has grown continually since then, expanding its portfolio from baked goods to its current five industrialized product categories – (1) biscuits, (2) cakes, (3) general chocolate goods, (4) Easter eggs, and (5) *panettones*.

The latter two product categories – Easter eggs and *panettones* – were the main drivers for the company's high growth, due to their boost in sales under Company A's own brand as well as the establishment of subcontracting agreements with big companies.

When the expansion took place, the company built an industrial unit to support the high-volume production of its industrialized products. Additionally, in order to improve the management of this industrial unit, the company has assigned a team for its management.

As the company kept growing, the industrial unit's management team implemented the current planning processes and their related decision-support models successively when they felt the need to adopt them.

Since Company A has established agreements with important retailers and contractors, it is aware of the importance of improving and formalizing its existing production planning processes in order to maximize profit from these agreements and not to lose them due to low service level (the loss of one of them will greatly affect the company's bottom line).

In its recent efforts to improve its production planning processes, the company has implemented a MRP system, and is currently focusing on the enhancement of its production control system.

Nevertheless, the company's top management feels that there is still room for improvement in its production planning process. Above all, it expresses a particular concern about the manufacturing of holiday products (Easter eggs and *panettones*) for three reasons. First, as mentioned previously, it has established agreements with big companies that contract Company A's production capacity for this type of products (the company does not subcontract the production capacity of its other product categories). Second, the seasonal alternation between production and idle times makes their production planning more difficult. Third, they have a relevant participation in the company's profits.

Therefore, due to the holiday products' importance to the company, the project focused on the improvement of their planning process.

1.2 Motivation/ Problem definition

In face of context described earlier, the project was motivated by the impact it brings to the company. As the academic literature review suggests, a formal and systematic production planning process can lead companies to achieve high efficiency and effectiveness levels. (ARNOLD, 1998), (CHASE *et al*., 2006), (HOPP; SPEARMAN, 2008).

It is worth mentioning that the project began with a wide-scope topic and the motivation derived from it, which were to improve Company A's production planning process concerning Easter eggs and *panettones*. Thus, the project did not try to force-fit a specific subtopic of production planning before assessing the company's status quo.

Only after the assessment of the company's production planning and the definition of the most relevant opportunities for improvement, the project defined which problems to target and how to address them.

1.3 Objective

This project aimed at identifying key opportunities for improvement in Company A's production planning and dealing with the main ones in order to assist the organization in making its decisional processes more robust, systematic and formal.

1.4 Relevance of the Project

As mentioned earlier, Company A has grown rapidly and has implemented its decision-making processes and related models successively in order to support the planning needs of such growth. Currently, the company is focused on enhancing and formalizing the existing processes in order to ensure that it is fulfilling the demand of its large base of customers (retailers and contractors) and, at the same time, maximizing its profit.

The project expects to be relevant for the company by assisting it in these improvement efforts. The first expected contribution is the assessment of the company's current decision-making processes and the identification of opportunities of improvement, which can serve as a guide for the company's future improvement projects. The second contribution relates to the development of solutions by this project that deal with the main points of improvements among those previously identified.

1.5 Outline of the Thesis

The rest of this report is organized as follows.

Chapter 2 contains the literature review of the main topics used in the assessment of Company A's production planning. Since this assessment resulted in an action plan that involved the development of the decision-support models, the chapter also contains the literature used for their development and implementation proposal.

Chapter 3 describes the methodology adopted in the development of this project, with the steps and procedures adopted during the assessment of the company, as well as during the development of the decision-support models.

Chapter 4 begins by providing an overview about the company, its products and its production processes. Afterwards, the chapter presents the company's current production planning through the perspective of the hierarchical production planning framework and the process-mapping tools SIPOC and BPMN. Finally, it ends by discussing the opportunities for improvement found in Company A's planning, and presenting the project's action plan.

Chapter 5 presents the line-balancing model developed for supporting Company A in its decision-making process during capacity planning. In order to do so, the model reproduces the company's production lines, and, therefore, the chapter's sections presents how the differences between the production processes of Easter eggs and *panettones* are contemplated in the model.

Chapter 6 explains the production-planning model developed to provide the company a systematic way to work with aggregate data and production costs in its production planning. In addition, the chapter contains the critical discussion of the results obtained in the model's verification and validation process.

Chapter 7 discusses the implementation of both models, the line-balancing model and the production-planning model. In order to structure and evaluate the implementation proposal of the models, the project adopted a four-stage framework, and the chapter's sections follow the same structure in the discussion.

Finally, chapter 7 contains the project's conclusion, presenting its synthesis, the main results obtained, and the next steps that the company must follow according to the obtained results.

2 LITERATURE REVIEW

This chapter presents the main theoretical concepts employed in the project – from the academic basis to assess the company's status quo to the development of the decision-support models and their implementation proposal.

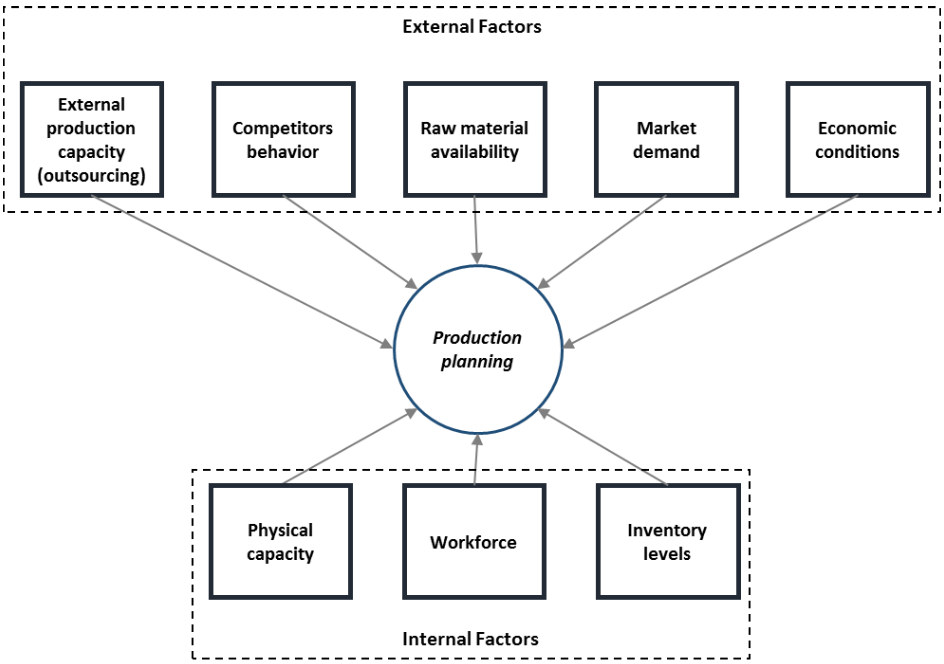
The literature review initially focused on the rationale behind production planning in order to set a framework suitable to identifying the company's needs and opportunities for improvement. Afterwards, the literature review covered the topics of capacity planning and aggregate production planning, because the company presented relevant points of improvement in these areas. These topics were key to supporting the development of the decision-support models.

The literature review also analyzed academic papers on how to regard production planning as a process in order to support the assessment of the company's current production planning and to design an implementation proposal that suits the company's context.

2.1 Production Planning

Since the ongoing management of manufacturing organizations entails several internal and external factors (as depicted in Figure 1), the approach to production planning is based upon one major premise, which is "problems at different levels of the organization require different levels of detail, modeling assumptions, and planning frequency." (HOPP; SPEARMAN, 2008, p. 434).

Figure 1 - Factors considered in Production Planning



Source: Adapted from Harrison; Petty (2002)

Such a premise implicitly suggests that there is the need of using separate tools for different sorts of problems and that real-world problems are too complex to be addressed by one single model/ tool. Therefore, the planning of a manufacturing organization can be considered as a hierarchical process, which breaks down the decision problems into manageable sub-problems successively, from high-hierarchy to low-hierarchy layers (HARRISON; PETTY, 2002).

In order to structure the production planning as a hierarchical process, time horizons are created, and decision problems are classified in these time horizons according to the length of time over which their consequences persist:

- **Decision problems with long-term consequences:** These problems consider rough volumes and product mix in order to plan for capacity and staffing;
- **Decision problems with medium-term consequences:** These problems disaggregate the strategic choices to support decisions concerning material procurement, suppliers line up and negotiation of customer contracts;
- **Decision problems with short-term consequences:** These problems establish a detailed work schedule for the production execution and control.

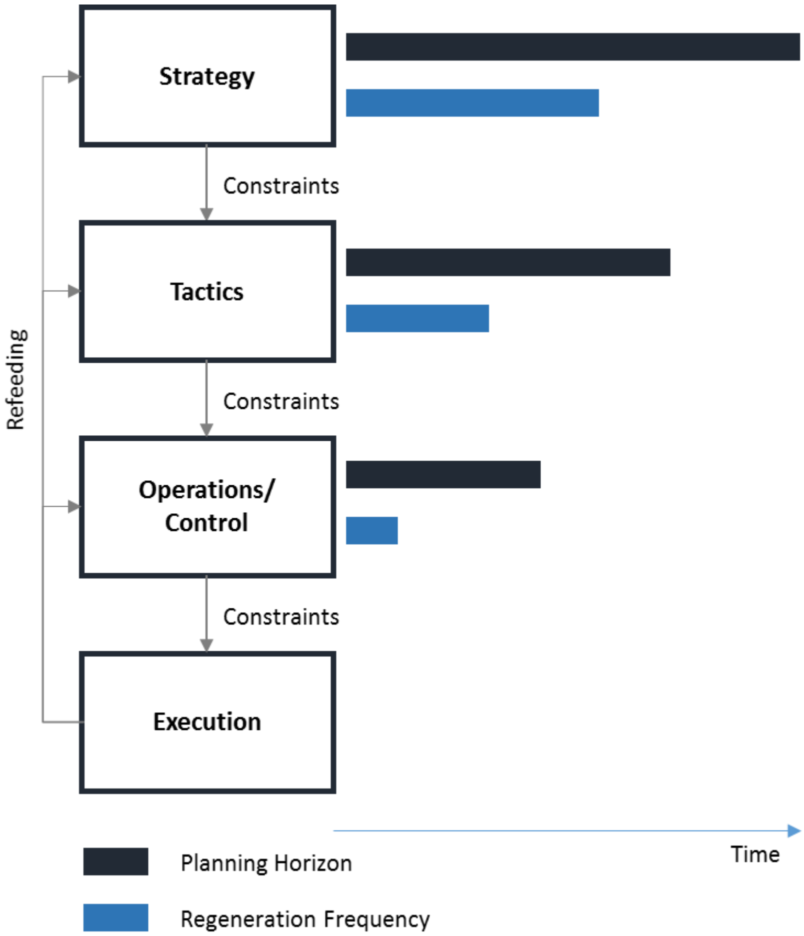
Hopp; Spearman (2008) labels these three main hierarchical layers as **(1) Strategy**; **(2) Tactics**; and **(3) Control**.

In addition to using time horizons as a criterion, the hierarchical treatment of the production planning process presents two other main characteristics intrinsic to the hierarchy levels. The first characteristic concerns the constraining effect of higher hierarchical levels on the following and lower ones. The second regards the level of detail in the hierarchical levels, which tends to increase as the levels cover shorter planning horizons.

For Hopp; Spearman (2008), the advantage of aggregating information in high-hierarchy levels is that it compels decision makers to focus on the right issues, and do not waste time and resources trying to predict unnecessary details. In addition, aggregate forecasts exhibit less variability than detailed ones – concept of **variability pooling**.

As the planning layers differ according to the required level of information and the covered time horizon, they consequently present diverse regeneration frequencies. In this perspective, low-hierarchy plans are revisited more often, and feed the high-hierarchy ones once they are reviewed (SANTORO, 2003). Figure 2 illustrates the diverse planning horizons and regeneration frequencies among the hierarchical levels.

Figure 2 - Hierarchical Planning Levels



Source: Adapted from Santoro (2003)

Table 1, adapted from Hopp; Spearman (2008), indicates the most common production decisions, how they are split in the hierarchical levels, and their respective planning horizons and regeneration frequencies.

Table 1 - Strategic, Tactical and Operational Decisions

Planning Horizon	**Planning Horizon Length**	**Regeneration Frequency**	**Representative Decisions**
Long Term (Strategy)	Year to decades	Quarterly/ Annual	Financial decisions Marketing strategies Product designs Process technology decisions Capacity decisions Facility decisions Supplier contracts Personnel development programs Plant control policies Quality assurance policies
Medium Term (Tactics)	Week to year	Weekly/ monthly	Work scheduling Staffing assignments Preventive maintenance Sales promotions Purchasing decisions
Short term (Operations/ Control)	Hour to week	Real time/ daily	Material flow control Worker assignments Machine stop decisions Process control Quality compliance decisions Emergency equipment repairs

Source: Adapted from Hopp; Spearman (2008)

As observed in Table 1, each hierarchical level – Strategy, Tactics, Operations/ Control – entails several decisions. For this reason, Arnold (1998) posits that it is necessary to take into account four criteria to frame properly a manufacturing system's planning process.

The first three criteria – **Planning Horizon Length**, **Regeneration Frequency** and **Level of Detail** – allow decision makers to create the three hierarchical levels described earlier – Strategy, Tactics and Operations/ Control. With the fourth criterion, **Purpose**, decision makers can generate planning modules within each level in order to better develop a production planning process for a certain manageable manufacturing sub-problem.

The purpose of each module involves its final outputs (decisions to be made) and its required inputs.

The consideration of these four criteria enable the mapping of all decision-related information flows within a manufacturing system.

2.2 Hierarchical Production Planning Frameworks

Hierarchical Production Planning (HPP) frameworks takes into account the four criteria described by Arnold (1998) – Planning Horizon Length, Regeneration Frequency, Level of Detail and Purpose – in order to structure the production planning in hierarchical levels and their corresponding planning modules.

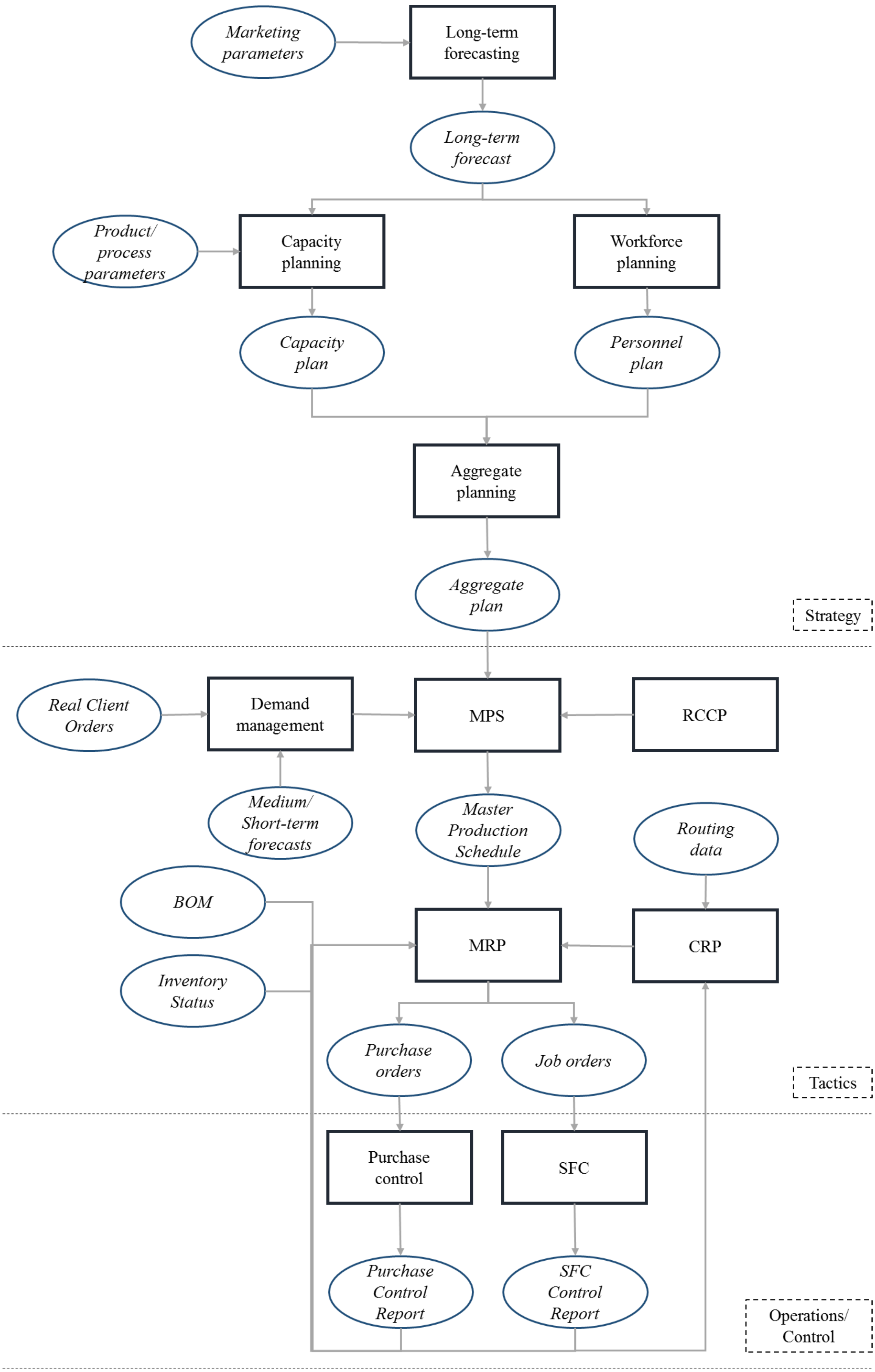
The importance of such frameworks are twofold. First, they support the assessment of companies in order to pinpoint gaps and points of improvement in their planning processes. Second, they are critical in the development of a brand new planning system or the implementation of a new planning module in an existing planning system, as they are a tool that enables the outline of the planning processes by aligning their timing and functions.

At this point, it is worth highlighting that HPP frameworks deals with manufacturing strategy, and not business strategy.

According to Hill (2000), **business strategy** defines the overall direction of the company, providing top-level guidelines to all operations within the entity (manufacturing and non-manufacturing ones). Conversely, **manufacturing strategy** is concerned with producing items to meet the target guidelines given by the business strategy in the most effective and efficient manner possible. Therefore, decisions (such as which business to be in, the nature of the product designs, and so on) are out of HPP frameworks' scope.

Figure 3 illustrates the HPP framework that the project considered when assessing Company A. The framework is adapted from Arnold (1998) and Hopp; Spearman (2008). The rectangular boxes in Figure 3 represent the planning modules, and the oval ones denote the inputs/ outputs of these modules.

Figure 3 - Hierarchical Production Planning Framework



Source: Adapted from Arnold (1998) and Hopp; Spearman (2008)

As observed in Figure 3, the modules of the strategic level involve decision problems related to establishing a production environment capable of meeting the plant's overall long-term goals. As previously discussed, they embrace planning decisions whose consequences persist for years and even decades, and are revisited/ reviewed quarterly or annually.

The starting point for this strategic planning is the **long-term forecasting**, which is responsible for generating expectations about the future in the long run. There are several forecasting methods, from qualitative to quantitative ones. Since long-term forecasting is out of the project's scope, the methods are described briefly below, according to Chase *et al.* (2006)'s work.

- **Qualitative methods:** They attempt to use expertise and knowledge of people in the development of future scenarios. Examples of these methods are Expert Panels/ Delphi Method, Market Analogies, Market Search, among others;
- **Quantitative methods:** The prediction of future scenarios relies on mathematical models that use numerical measures of the past. These methods are usually split into two approaches: causal and time series;
    - **Causal/ Relational models:** They predict a future parameter as function of other parameters (e.g. regression models);
    - **Time series models:** They predict a future parameter as a function of its own past values (e.g. Moving Average, Exponential Smoothing, Winters Method, and the like).

The future projections from the long-term forecasting provide the basis for planning the overall plant structure to meet them in terms of equipment and workforce. The **capacity planning** makes use of the forecasts along with product and process parameters to determine the need for physical equipment, that is, how much and which kind of equipment to purchase. The **workforce planning** bases itself on the demand forecasts to generate a personnel plan for hiring, firing and training according to the company's labor policies.

At this point, it is important to highlight that these issues embrace many other aspects of which the decision-maker must be aware, such as factory floor space, materials handling systems, staffing levels, and so on. Moreover, the decision made may even implicate not satisfying completely the future demand due to cost and flexibility issues.

The **aggregate planning** is the link between the strategic choices taken in the capacity and workforce planning, and the subsequent tactical decisions.

In general lines, an aggregate plan specifies how much of each product family to produce over time while considering constraints on demand, capacity and raw material availability. This plan seeks to minimize the production cost (or maximize profit) while still meeting the demand targets (there is the possibility of creating a model that analyzes the trade-off of not satisfying the demand completely).

The aggregate planning can also be conducted in tandem with the workforce planning (HOPP; SPEARMAN, 2008). In this case, it considers labor-related costs to specify the timing of hires and layoffs, the usage of temporary hires, and the usage of shifts and overtime.

Hoop; Spearman (2008) stresses the importance of aggregate planning, because it assesses production and economic parameters together in a comprehensive way, solving large problems quickly and providing important insights to the planning process. In addition, it enables decision makers to perform sensitivity analyses and revise the previously made decisions in the capacity planning and in the workforce planning (if not conducted in tandem).

It is important to notice that some works, such as Oliveira (2011)'s and Bushuev (2013)'s, consider aggregate planning as a tactical module, since it starts to take a closer look at production constraints, production mix demands and economic variables; while other works, such as Takey (2004) and Hopp; Spearman (2008), regard it as a strategic module.

Concerning this issue, Buxey (2003) conducts a survey to support the strategic view regarding aggregate planning. According to Buxey (2003), the main function of the aggregate production module is to generate insights on production rates and workforce levels, and its classification as a tactical module conveys the wrong message to decision makers. A tactical classification makes planners focus on more detailed/ tactical information, which is irrelevant given the existing uncertainty level in the medium/ long term.

The tactical part of the HPP framework begins with the **master production scheduling** (MPS), which is responsible for defining in a disaggregate way the production and inventory levels. This definition is based on the aggregate outputs from the strategic modules and the real client orders provided by the **demand management**. In order to prevent the generation of infeasible plans by the MPS, the **rough cut capacity planning** (RCCP) module validates them by considering the manufacturing system's capacity constraints.

The **material requirement planning** (MRP) uses the MPS's disaggregated/ detailed plan (i.e. part number, quantity, due date) to generate scheduling orders.

At this point, it is important to mention Harrison; Petty (2002)'s work, which stresses that the master production schedule must always drive the MRP instead of pure sales (client orders). Their argument is that the MPS is able to move production requirements into underloaded periods. Thus, it can minimize setup changeover disruptions, and deal with with lumpy or seasonal demands. Conversely, the MRP is not able to do so due to its short planning time horizon.

Besides requiring information concerning the independent demand (demand for end items), contained in the master production schedule, the MRP also needs the items' inventory status and the information about the linkages between the end items and the lower-level (demand-dependent) items, which is contained in the bill of materials (BOM). With all this information combined, the MRP can originate scheduling orders (part number + quantity + due date), which may be **purchase orders** (sent to vendors) or **job orders** (sent to the production plant).

It is important to observe that MRP systems alone just involve launching orders to the manufacturing system, as if the environment remained static after the release of such orders. However, the reality is that a manufacturing environment has an intrinsic dynamic characteristic, and its conditions are constantly changing due to sales variations, supplier variations, manufacturing variations, stores problems, engineering changes and planning changes. Thus, in face of such changes, the orders originated by the MRP system may become inadequate after a while (HARRISON; PETTY, 2002).

This is the reason why the **shop floor control** module is relevant. A well-designed SFC module controls the flow of material through the plant, and is a natural means to collect data and to feed the MRP module (HOPP; SPERAMAN, 2008).

Hopp; Spearman (2008) assigns two main functions to shop floor control: **job dispatching** and **input/ output control**.

Job dispatching entails the arrangement of job orders in order to keep manufacturing times low, machine utilization high, and setup times low, while maintain the due date integrity of the job orders.

There are at least 100 different dispatching rules present in the operations management literature. Two of the simplest, yet vastly adopted, rules are the **shortest process time** (SPT) and the **earliest due date** (EDD) (HOPP; SPEARMAN, 2008).

- **Shortest Process Time** (SPT): Arrangement of job orders according to their processing time, with the shortest jobs first in line. The idea is to clear out small jobs, and get them through the plant quickly, decreasing average manufacturing times and increasing machine utilization;

- **Earliest Due Date** (EDD): Organization of job orders in accordance to their due date, with the jobs closest to their due dates first. Usually, companies adopt the EDD when the jobs have approximately the same size, and routings are consistent.

The **input/ output control** is responsible for monitoring the Work-In-Progress (WIP) level throughout the manufacturing system, at each workstation, and generating detailed data about the manufacturing running.

The detailed feedback about the operations execution, provided by the shop floor control, contributes to the implementation of the **capacity requirements planning** (CRP) module, which is responsible for performing a detailed capacity check on the feasibility of the orders that the MRP generates, and preventing that infeasible orders are launched to the manufacturing system (HOPP; SPEARMAN, 2008). Harrison; Petty (2002) also states the need of an adequate shop floor control for the implementation of CRP, and attributes the lack of a proper SFC as the main reason why a majority of manufacturers still do not adopt CRP.

Besides the shop floor control module, Harrison; Petty (2002) also stresses the relevance of another control module, which is the **purchase control**. The purchase control tracks the launched purchase orders, and checks whether they are proceeding according to their due dates.

These two modules – the SFC and the purchase control – create a formal control mechanism that takes into account the ever-changing conditions of the manufacturing systems, and contribute to the tight alignment between planning and execution.

2.3 Capacity Planning

In a general business sense, capacity is regarded as the amount of work that can be done during a specific time period (ARNOLD, 1998). For planning purposes, capacity is usually broken down into three distinct time horizons – long, medium and short term (CHASE *et al.*; 2006).

- **Long-term capacity planning**: It covers periods above one year and involve productive resources that require a lot of time to be installed or eliminated, such as buildings and equipment;

- **Medium-term capacity planning**: It usually generates monthly plans for the next six to eighteen months. In this case, the capacity can be altered in face of alternatives such as hiring, firing, outsourcing, additional shifts and overtime. Aggregate planning is of great support in the evaluation of these alternatives;

- **Short-term capacity planning**: This sort of capacity planning covers less than a month, and it relates to the process of daily or weekly production scheduling (including options such as alternative routings and decrease of setups). It is conducted in tandem with MRP.

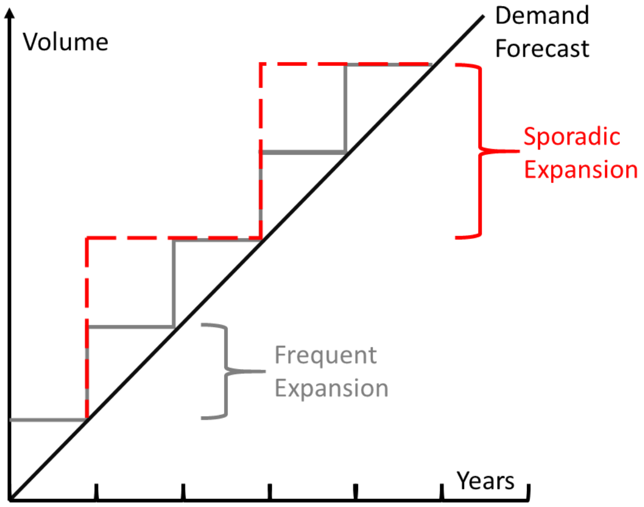
Long-term capacity planning (also known as strategic planning, facility planning, capacity expansion plan, tool procurement plan, tool portfolio, or resource portfolio) is the focus of this chapter, since one of the project's developed models involves this subject.

Strategic capacity planning is a critical module in production planning for two reasons. First, its output has a strong impact on the company's bottom line, as it determines the total level of capital-intensive resources to support the company's long-term competitive strategy. Second, it is at the top of the hierarchical production planning, and, consequently, its output affects all the following low-hierarchy planning modules, having a long-lasting influence on the company's service level, cost structure, as well as inventory and personnel policy (HOPP; SPEARMAN, 2008).

When planning strategically for capacity, Chase *et al.* (2006) highlights the three main issues to consider:

- **Balance within the system**: In a perfectly balanced plant, the outputs from one production phase to another fit perfectly in terms of quantities and timings. In real plants, there are misbalances in production phases – the bottlenecks. One of the main initiatives to tackle bottlenecks is through additional installation of equipment and outsourcing. It is important to mention that flow lines are likely to be unbalanced, mainly because capacity is usually available in discrete-size increments, which sometimes makes it impossible to match the capacity of a certain station to a particular target (HOPP: SPEARMAN, 2008);
- **Frequency of capacity expansions**: There is a trade-off between frequent and sporadic capacity expansions. Frequent expansions incur more costs related to the constant changing of equipment and the price difference between them, in addition to repeatedly stopping production due to installs. Conversely, sporadic expansions relate to longer unutilized capacity, whose invested capital could be allocated to other matters. Figure 4 illustrates the cases of frequent and sporadic expansions. It is important to mention that, in the case of sporadic expansions, aggregate planning can support the efficient allocation of production and workforce levels while the utilization of capacity is still low;

Figure 4 - Frequent Capacity Expansion versus Sporadic Capacity Expansion



Source: Chase *et al.* (2006)

- **External sources of capacity**: Planning for capacity also embraces the analysis of the trade-off between outsourced and in-house production. This analysis embraces not only quantitative aspects, but also qualitative ones, such as competitive positioning and dependence on third parties.

Consistent with and complementary to the issues raised by Chase *et al.* (2006), Hopp; Spearman (2008) also suggests the main questions to address when planning for long-term capacity:

- **How much and when should capacity be added?** : This issue concerns whether the company must expand its capacity in anticipation of future demand or when the demand has already developed. If the decision is to anticipate the demand, another question that needs an answer is how far into the future the planning should cover. This question is strictly aligned with Chase *et al.* (2006)'s issue concerning the frequency of capacity expansions;
- **What type of capacity should be added?** : In line with Chase *et al.* (2006)'s external sources, this question concerns the flexibility of the expansion in terms of the types of equipment (dedicated vs universal) and the sources of capacity (such as outsourcing vs in-house production). This question is key when dealing with products whose lifetime is lower than the expansion equipment's lifetime;
- **Where should additional capacity be added?** : It regards the decision of whether the expansion must be made in an existing facility or in a new one. Generally, it is more expensive to build a new facility than expanding a new one. Yet, if planned properly,

the new facility can provide long-lasting efficiencies with regard to marketing and distribution, for instance.

Regarding the last question – "Where should additional capacity be added?" –, Hopp; Spearman (2008) reinforces the importance of distinguishing two different capacity-planning scenarios: (1) modifying an existing production line and (2) designing a new production line.

Modifying an existing production line is often easier than designing a new one, because the modification analysis encompasses the 'cost vs operational performance' assessment of a limited number of improvement alternatives, which can be substituting the existing machines, adding more machines, and reducing the existing machines' variability.

Designing a new line is more complex, as there are many more options to consider. In a new line, planning is not constrained by existing machines, facilities, and structure – the problem presents much more degrees of freedom. Therefore, the new line design overlaps important issues of materials handling, physical plant layout, storage and warehousing, office planning, facility services, and the like.

2.3.1 Capacity Planning Models

In its review of the existing solutions to strategic capacity planning, Geng; Jiang (2009)'s work highlights three main methods:

- **Static Capacity Models**: Usually implemented with the use of spreadsheets, they allow the decision makers to inquiry about the static behavior of the manufacturing systems. Their widely adoption is due to their ease of use, despite their highly aggregate approach and their consequent lack of accuracy;
- **Mathematical Models**: They involve the application of linear programming (LP) or stochastic programming (SP) to find optimal solutions. LP models usually do not provide sufficiently robust solutions, as they do not contemplate uncertainty. Conversely, solutions from SP models are robust, yet they tend to overlook the manufacturing systems' operational performance (e.g. cycle time);
- **Neighborhood Search Models (mostly Simulation Models)**: The application of these models entails a local search (trial-and-error approach) around an existing decision to find a near-optimal solution. Thus, they present a tight fit with capacity planning when dealing with the modification of existing production lines. Neighborhood search models are able to provide performance-and-uncertainty-based solutions, yet decision makers tend to develop models that rely on too much data.

> Geng; Jiang (2009) reinforces that, when planning for strategic capacity, one must be careful not to input much more information than necessary at such a stage.

With regard to **static capacity models**, Arnold (1998), Chase *et al.* (2006) and Hopp; Spearman (2008) provide models that are easy to use and quick at finding a suitable capacity plan.

In general lines, Arnold (1998) and Chase *et al.* (2006)'s models are based upon the projection of the forecasted demand throughout the planning horizon. With this projection, the decision makers compare the required capacity to fulfill the demand with the available one, making adjustments to match them.

Hopp; Spearman (2008)'s model contributes to the discussion of capacity planning by positing that decision makers usually deal with multiple objectives in this sort of planning, since it does not only involve strict manufacturing and capacity issues, but it also embraces financial aspects. For this reason, Hopp; Spearman (2008) considers two clusters of parameters. The first one entails manufacturing-related/ operational dimensions, such as the mean effective process time for the machines and the number of machines in each workstation. The second embraces financial-related costs, which associate with the equipment purchase cost and install cost. With these two clusters defined, Hopp; Spearman (2008)'s procedure for capacity planning can be summarized as the following:

1. **Definition of the desired long-term operational performance**: Strategic decision regarding the overall operational performance of the manufacturing system, which can be defined in terms of required throughput and/ or maximum cycle time;
2. **Design and balancing of the possible capacity-feasible configurations**: Design of the several configurations that are able to meet the target throughput and/ or cycle time. The design of these configurations involves issues such as substituting the existing machines, adding more machines, and reducing the existing machines' variability;
3. **'Cost vs Operational Performance' assessment**: Assessment of the improvement alternatives. Since the capacity expansions are frequently available in discrete-size increments, the exact match between the target performance and the improvement alternatives' performance is rare. In these cases, the decision maker analyzes if the additional cost and operational performance of each alternative is worth it.

With respect to **mathematical models**, Zhang *et al.* (2004) and Huang; Ahmed (2009) provide two examples of stochastic programming that provide robust solutions to the decision-making process of capacity expansion. Yet, as indicated by Geng; Jiang (2009), the objective functions of these models are focused on the financial aspect of capacity planning, as they aim at minimizing costs. Thus, operational performance (e.g. cycle time) is a secondary concern for them.

Concerning **neighborhood search/ simulation models**, Discrete Event Simulation (DES) models is one of the most commonly used techniques for evaluating the different alternatives of system configurations (NEGAHBAN; SMITH, 2014).

In Negahban; Smith (2014)'s comprehensive review of simulation publications, they highlight the flexibility of simulation models, which can be used as support tools in the study of manufacturing systems through several perspectives/ hierarchical levels. Harrison; Petty (2002) also reinforces simulation's wide range of applications in a variety of production-planning fields, attributing such a wide range to the descriptive nature of simulation and the insightful understanding it provides in any hierarchical level – operational, tactical and strategic.

Negahban; Smith (2014)'s review presents examples of simulation being applied to systems design and balancing, such as cases of strategic capacity planning, as well as cases of applications towards operational issues of manufacturing systems, such as scheduling.

On the topic of the design and balancing of manufacturing systems, Negahban; Smith (2014) cites papers that regard simulation as a tool for the conceptual design and pre-study of manufacturing systems through virtual factories. In these cases, the application of simulation along with bottleneck analysis, work measurement, facility layout analysis, among others, is a tool to derive and evaluate different design alternatives for a manufacturing system.

Geng; Jiang (2009) also regards simulation as a key tool to evaluate manufacturing systems under conditions where operational performance (for instance, cycle time and production capacity) is the main concern. In these cases, simulation is adequately accurate to compute the operational performance as a function of resource availability, production rate, and the like.

2.4 Aggregate Production Planning

Aggregate production planning (APP) is concerned with determining the production rate and workforce level that should be set over a given horizon in order to meet demand and minimize total expected cost (or maximize total expected profit) (BUSHUEV, 2014).

According to Chase *et al.* (2006), a proper aggregate plan is critical when dealing with productions systems subject to seasonal demand, as it supports the decision of which production strategies to adopt, which are the following:

- **Chase strategy**: In this strategy, the production volume varies according to demand. The increase of production in demand peaks is commonly obtained through the hiring of temporary workers and/ or increasing work hours (number of shifts and overtime). An alternative way is outsourcing production to reliable suppliers. This strategy tends to present lower inventory levels at the expense of higher labor/ outsourcing costs;
- **Level strategy**: In this strategy, inventories produced during underloaded periods absorb demand fluctuations. It presents relatively constant labor and outsourcing levels, and, thus, the main cost is related to inventory carrying;
- **Mixed strategy**: This strategy results from the combination of the previous ones, as the production planning seeks to balance costs associated with production, inventory, labor and outsourcing.

It is important to observe that production capacity is usually fixed in the medium/ short term due to long equipment installs, syndical agreements, and time-consuming hiring and training processes. Thus, aggregate planning enables decision makers to jointly assess production and economic parameters in face of these capacity-related constraints, and choose which is the most efficient strategy to adopt.

Several different formulations of the APP module are possible, depending on which variables/ costs the decision maker wants to address and balance (timing of staffing additions, which products to subcontract, and so on). The following subsection describes them.

2.4.1 Aggregate Production Planning Models

According to Nam; Logendran (1992), aggregate planning models can be classified in three main clusters: linear programming models, mixed-integer linear programming, and heuristic models.

- **Linear Programming (LP) models**: The simplest production-planning models, which allow the analysis of numerous linear constraints and variables. Hopp; Spearman (2008) posits that, since APP covers speculative long-range data, it generally does not make sense to use anything more sophisticated than LP models in most aggregate planning situations;
- **Mixed-Integer Linear Programming (MILP) models**: These production-planning models include integer variables, increasing further the modeling capability. For Kempfy *et al.* (2011), MILP models tend to be more accurate than LP ones, because they do not force cost functions to be linear, and, consequently, they guarantee solutions closer to reality;

- **Heuristic models**: These models are used when the planning problem is too complex to be solved by optimizing algorithms alone. In these cases, LP and MILP models are used to generate candidate plans, which are examined, combined and altered by the decision makers though heuristic methods.

Hopp; Spearman (2008) considers a general scenario to illustrate in a didactic way the potential of the **LP models**. In their work, they present a **multi-product mix** problem with the assumption that sales unmet on time are not lost; rather, the company incurs a **backordering** penalty. Another relevant point in their work is the contemplation of the products' **gross margin** as a result of their prices deducted essentially from raw materials costs. **Inventory carrying costs** (cost to hold one unit of product for one period) are computed separately as a percentage of the item value, which takes into account physical storage costs as well as financial costs. With regard to the capacity constraints, they are assumed to be linear due to the chosen model type. Consequently, they are represented by the quantity of resource units required to produce one product unit (worker-hours, machine-hours, component units, and so on).

It is important to mention that Hopp; Spearman (2008) considers the possibility of increasing available production time via the use of **overtime** and the **resizing of the workforce** with hires and layoffs. However, due to the linear consideration of the workforce, the assessment of the number of employees is hindered, as the decision maker needs to evaluate the total amount of worker-hours, convert them to number of workers, and then make adjustments to find a feasible integer number. Gramigna (2002)'s LP model for a company of the food sector also regards the workforce in terms of worker-hours and presents the same drawback.

On its turn, Takey (2004) addresses the workforce in a different way, by using a **MILP model**. The model does not represent the workforce linearly in terms of worker-hours. Rather, it assumes that each production line requires a fixed number of workers. The implementation of such assumption depends upon the use of a **binary variable** that associates the number of workers with the necessary quantity to run the production lines.

Some studies modify the traditional mathematical programming techniques (LP and MILP models) claiming to obtain more precise and robust models this way, as they try to tackle the uncertainty present in medium/long-term parameters (market demand, available resources and capacity, relevant operating costs, among others).

Studies, such as Sim (2004) and Munhoz; Morabito (2014), use the **robust optimization** approach to take into account the uncertainty in some model parameters. For instance, Munhoz; Morabito (2014) develop a LP model to support the decision process of a citrus products manufacturer and incorporate the uncertainties of some parameters (the ratio of the juice, the scrap yield and the fruit availability from suppliers) to the model. In this case (and others cases that adopt the robust optimization approach), the model leads to a conservative solution, because it addresses the problem of data uncertainty by ensuring the solution's feasibility for the worst cases of the parameters.

Another way to consider the imprecision in the parameters is the introduction of the **fuzzy set theory** in LP models. Studies, such as Rommelfanger (1996) and Gholamian *et al.* (2015), make use of the fuzzy optimization method with the statement that demand forecast, operating costs as well as labor and machine capacity are uncertain in a medium/ long time horizon.

There are also studies that make use of probability distributions in the model. Wang; Liang (2005) presents one example of this approach, by solving a multi-product aggregate production planning problem with **possibilistic linear programming**. Such approach adopts the pattern of triangular possibility distribution for imprecise coefficients – such as regular time, overtime, subcontracting, inventory carrying, backorder, hiring and layoff costs. The addition of probabilistic elements leads the model to present multi objectives, which are the minimization of total costs, the maximization of the possibility of obtaining lower total costs, and the minimization of the risk of obtaining higher total costs.

It is important to mention that some scholars – such as Hopp; Spearman (2008) and Buxey (2003) – argue that precise data and intricate modelling are impractical in most aggregate planning situations, since they involve speculative long-range data. Thus, methods, such as robust optimization, fuzzy sets theory and probabilistic approaches, should be used with discernment.

Hopp; Spearman (2008) also states that the plan generated by the APP module will never be followed exactly no matter the accuracy of the input data nor the model sophistication, because the production plan is susceptible to unanticipated events that could not possibly have been considered in the module. In this context, the mark of a good long-range production plan is its flexibility and reliability in face of such contingencies. According to Hopp; Spearman (2008), the use of a **correction factor** linked to the resources capacity to account for their aggregate effect of unforeseen events is sufficient in most APP situations.

Buxey (2003) shares the same opinion by arguing that the addition of extra penalties and constraints does not make the models much more precise and is unreasonable in most cases. Rather than designing sophisticated modules, he supports the design of a robust decision process characterized by constant revision/ regeneration of the production and workforce plans as time evolves.

Besides the technical elements, the Hopp; Spearman (2008)'s argumentation is also supported by a human/ organizational rationale. For them, it is desirable to keep a model simple in order to keep it understandable across all the parts involved in the production planning and to 'sell' the planning results to the business executives. Moreover, they claim that no single aggregate production planning module is right for every situation, and even a module tailored to a company's situation in a specific year is subjected to changes in the following revisions. Thus, they preach that employees' understanding concerning APP to stimulate their constant engagement in developing new APP modules is more important than creating complex models. Such argument is in line with their principle of **iterative model development**, which is based upon the observation that the APP process (modelling, analysis and decision-making) is almost never conducted in a single pass. The solution from one version of a model often suggests the development of an alternate model to investigate the dynamics regarding the production system and model assumptions.

2.5 Process Mapping

No assessment can be considered successful unless it provides a thorough understanding of how the constituent elements of an organization interact with one another, because it is these interactions that constrain the systems (SALAMA *et al.*, 2009).

This rationale applies for the assessment of production planning processes. Without a proper understanding of how the information flows run through a company in its decision-making processes, the assessment of the company's production planning is incomplete, and the suggested planning modules/ decision-support models run the risk of being disregarded if they do not fit the company's environment.

As previously explained, HPP frameworks support the assessment of companies in a way that they pinpoint gaps and points of improvement in their planning processes. Moreover, they are a valuable tool to outline planning processes throughout the company under the perspective of their timing and functions. Nevertheless, HPP frameworks are myopic, as their general outline overlooks information flows and their participating elements.

Therefore, HPP frameworks need to be complemented in the development of a brand new planning process or in the implementation of a new planning module in an existing planning process.

The existing production-planning literature focuses on the development of the planning modules, and few papers regard the issue of a methodological implementation of such modules. Consequently, the scope of the literature review was broadened and contemplated wide-ranging papers on processes diagnosis and changes implementation.

Mast; Lokkerbol (2012) emphasizes the importance of process mapping in non-manufacturing task environments. Contrary to manufacturing task environments in which there are tangible outputs (products) to map, non-manufacturing environments (production-planning processes included) usually lack of a process view due to their intangible outputs. Therefore, process mapping can provide the understanding of these non-manufacturing environments in order to evaluate and improve them.

Due to the importance of process mapping, Mast; Lokkerbol (2012)'s study focuses on the DMAIC procedure (acronym standing for Define, Measure, Analyze, Improve and Control). DMAIC's original task-domain was variation reduction, especially in manufacturing processes. Later, it started being applied in practice as a generic process improvement methodology.

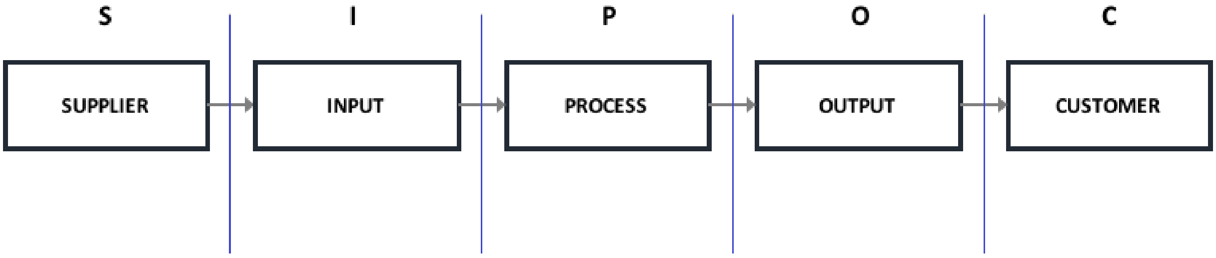
In DMAIC, process mapping takes place in the Define phase, and one common tool that is used in this phase is the SIPOC (acronym for Supplier-Input-Process-Output-Customer).

According to the SIPOC theory, all organizations are systems built upon five elements, which are interrelated and interactive:

- **Supplier**: Organizations and/ or departments that provide information, materials or other resources to core processes;
- **Input**: The resources provided by the suppliers to the process, that is, the outputs from the upstream departments;
- **Process**: Set of activities that convert the input into output;
- **Output**: Products, services and/ or information derived from the process, that is, the requirements of downstream departments;
- **Customer**: Person, organization or department that receives the output – the customer can be an external or an internal one.

Cao *et al*. (2015) posits that the SIPOC diagram is a suitable tool to outline companies' processes, as it demonstrates sets of activities across functional departments' boundaries. The five-part analysis effectively identifies the constraints between upstream and downstream sectors in order to assess the material and information flows. Figure 5 presents SIPOC diagram's general outline. It is worth highlighting that its application varies according to the users' objectives. This way, the diagram can be used as a means to analyze a process at a high level, without splitting the element '**process**' in its set of activities, or at a detailed level, where the analysis involves an in-depth representation of the process steps.

Figure 5 - SIPOC Diagram's General Outline



In her work, Zago (2013) uses the SIPOC diagram to study the implementation of a production-planning system in a Brazilian dairy company. In this case study, the information flows related to the aggregate production planning are broken according to SIPOC's five elements in order to assess the involved parameters and functional departments.

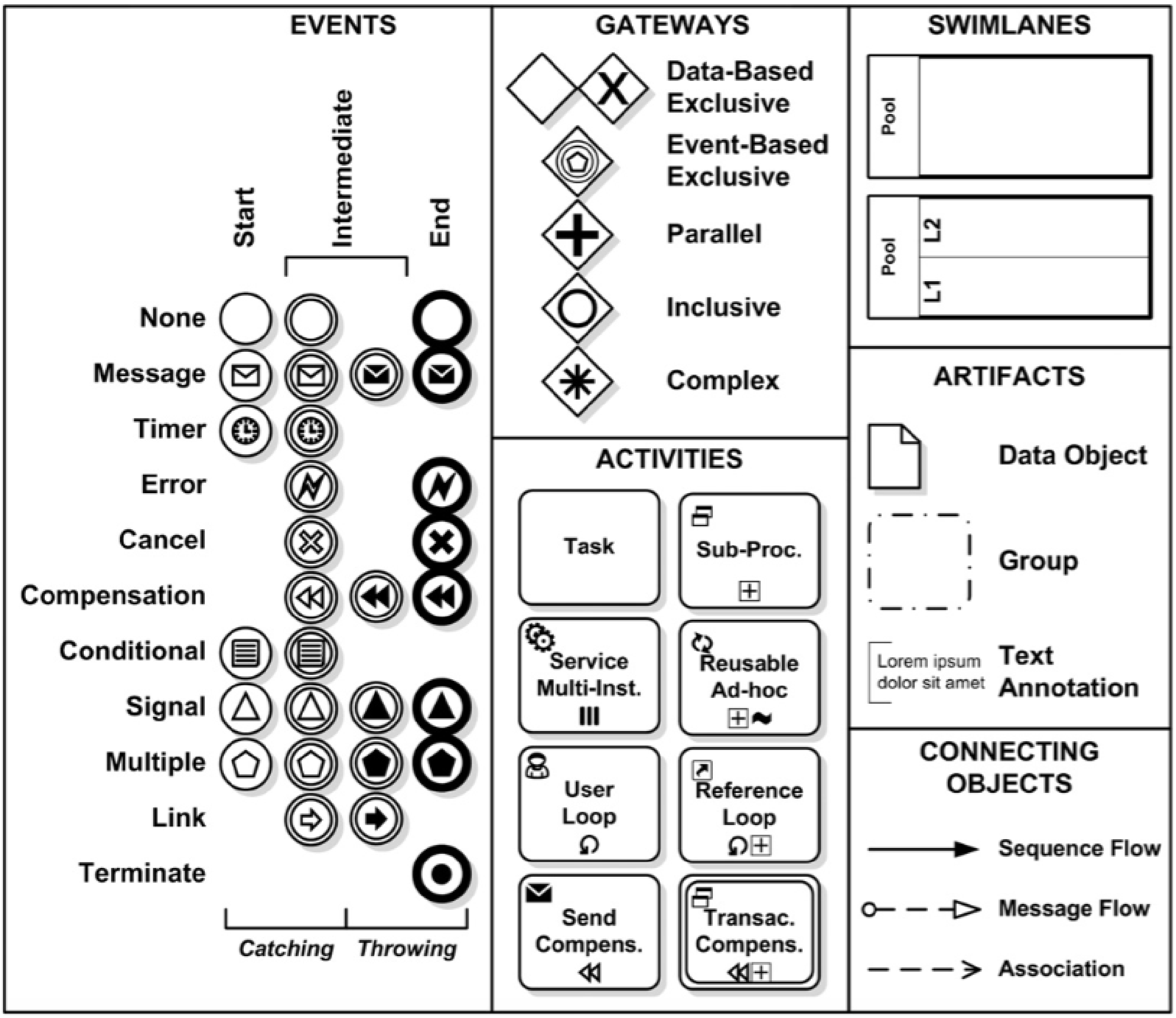
The work by Netto (2004) suggests another tool, rather than the SIPOC, as an appropriate tool for process mapping: the IDEF0 (**I**ntegrated **Def**inition).

In his discussion about the importance of process mapping in the improvement of existing processes, Netto (2004) empirically observes that most of the mapping approaches adopt flowcharts as their main tool, focusing on the sequences of tasks and illustrating 'how' the systems work. In his argumentation, process mapping must also involve 'what' the systems work, that is, the inputs and outputs of each process. For this reason, Netto (2004) suggests IDEF0 (**I**ntegrated **Def**inition) as a proper process mapping tool, since it involves the 'what' dimension. However, Netto (2004) also presents this tool's limitation regarding the treatment of data. The expected inputs in the theoretical conceptualization of IDEF0 are materials and objects. Thus, there is no clear indication of how to deal with data and their processing.

With regard to the Netto (2004)'s concern about the 'what' and 'how' dimensions of process mapping, the use of the SIPOC diagram already covers part of the IDEF0's scope, as it illustrates 'what' the systems work, that is, the inputs and outputs of each process. Yet, the SIPOC still needs to be complemented by another tool – dedicated to visually illustrating 'how' the systems work with data. This complementary tool can be the Business Process Model and Notation (BPMN).

BPMN is the *de-facto* standard for representing in a graphical way any kind of process occurring in an organization (CHINOSI; TROMBETTA, 2012). The BPMN provides a modelling language focused on describing the workflow of business processes, that is, the flow of procedures or activities that follow a predefined order to realize a business objective. It provides a graph-oriented notation that is readily understandable by any business user in order to improve processes implementation and monitoring. Figure 6 presents a summary of BPMN's elements.

Figure 6 - Summary of BPMN's elements



Souce: Chinosi; Trombetta (2012)

One relevant example of BPMN's application is given by Siller *et al.* (2008)'s case study, which uses BPMN for representing the running of tasks that must be carry out for the collaborative process planning between an original equipment manufacturer and its suppliers. In this case study, the use of BPMN generated the processes blueprints to ensure the orderly execution of activities and information flow in the subsequent implementation of the collaborative process planning.

It is important to reinforce that the BPMN describes the timing of each process, as it follows a flowchart rationale.

Therefore, its combined use with the SIPOC diagram is appropriate for defining blueprints for the implementation of planning processes. SIPOC's five elements – suppliers, inputs, processes, outputs and customers – embraces the 'what' dimension of planning processes. On its turn, the BPMN adds a sixth element – time – to the analysis, and covers the 'how' dimension of the production-planning processes.

3 METHODOLOGY

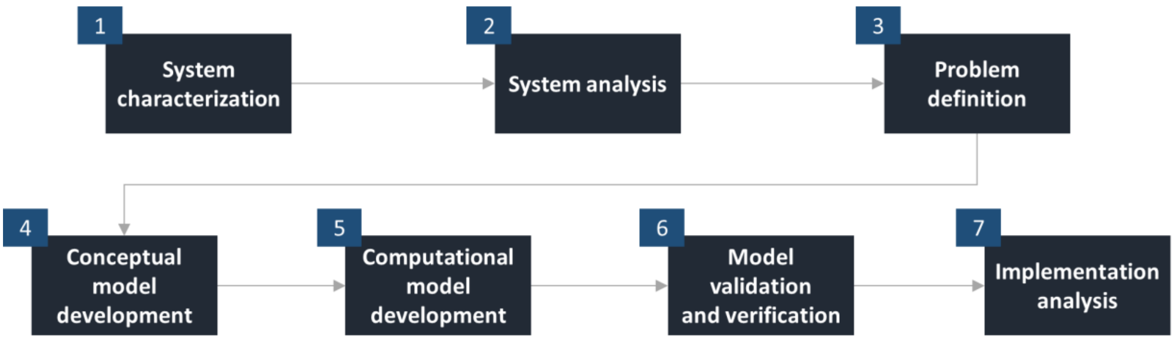
This project aimed at identifying key opportunities for improvement in Company A's production planning in order to assist the organization in making its decision-making process more robust, systematic and formal.

For this reason, the project's methodology initially involved standard problem-solving practices to assess the company's decisional process. After defining with which problem the project would deal, the resulting action plan consisted of the development of decision-support models. Therefore, the project's methodology also entailed modelling practices to ensure the proper development of the models.

Moraes (2004)'s proposed methodology for assessing, understanding and modelling manufacturing systems was suitable to this twofold characteristic of the project – an in-depth assessment of the company's current situation along with the development of decision-support models. Therefore, the project took Moraes (2004)'s methodology as a reference point and modified it with the addition of academic recommendations from other works, more specifically, Upton; Macadam (1997) and Altigan; McCullen (2011).

Figure 7 summarizes the methodology used in the project, and is followed by an explanation of each of its phases.

Figure 7 - Project Methodology



Source: Adapted from Moraes (2004), Upton; Macadam (1997) and Altigan; McCullen (2011)

The **(1) system characterization** and **(2) system analysis** are part of the preliminary assessment of the company in order to define the project's scope and objectives (**(3) problem definition**).

As proposed by Upton; Macadam (1997), the system characterization and analysis was conducted in two separate types of plant tours – preliminary **learning tours** and subsequent **assessment tours**.

According to Upton; Macadam (1997)'s recommendation, the primary objective of the **learning tours** is to broaden the knowledge base concerning the manufacturing running.

Conversely, the **assessment tours** have as their main objective the use of existing knowledge to evaluate a plant, rather than the acquisition of more knowledge.

The project's preliminary visits, the learning tours, analyzed the physical material flows within the plant. They focused on comprehending Company A's manufacturing processes and related production flows (including resources – machinery and workforce – and their usage characteristics).

A point highlighted by Upton; Macadam (1997), which was taken care with due care and attention, was the choice of the tour guide, who tends to present the plant through the perspective of his/ her job position. The project ensured that the PP&C manager guided the plant tour, as a means to perceive the company from a planning-based perspective. Moreover, the PP&C manager is the decision-support models' end user, which reinforces the importance of observing the company through his perspective.

The assessment tours focused on the information flows in the company's production planning process. Due to the great complexity revolving the production planning process, the assessment tours used the HPP framework along with the SIPOC and BPMN tools as guiding frameworks.

It is important to highlight that the assessment of the planning process did not consist of analyzing and asking specific questions about IT software/ solutions, nor focusing on management reports' numbers. In accordance with Upton; Macadam (1997)'s recommendation, it was considered as more insightful asking employees how they accessed the information they needed to carry their jobs and how this was tied to the decisions they needed to make. This kind of inquiry supported the comprehension about how the employees really made use of the information available in the company. The evaluation of the employees' attitude towards the decisional processes is crucial to developing a model that fits their needs and that have a long-lasting adoption.

Table 2 presents Company A's employees who took part of the assessment tours and the main topics discussed with each one of them. The discussions took the form of qualitative open-ended interviews with no fixed questions, as a means to assess the production planning at a macro level and then inquiry about the points, which seemed unclear in the participants' speech. The unclearness in the speeches indicated fuzzy areas in the company's production planning and, consequently, opportunities for improvement.

Table 2 - Interviews: Participants and Main Topics Covered

Participants	**Main Topics Covered**
President	• Overview on roles and responsibilities • Decision-making process concerning investments • Current challenges faced by the company
Operations Director	• Planning and production chronograms for each product category • Production planning structure • Current improvement projects
PP&C Manager	• Planning processes and related difficulties • Relationship with preceding and following planning departments • Data availability • Finished and WIP inventory management • Production control and management
Sales & Marketing Manager	• Relationship with customers • Sales and forecasting process • Communication with other departments and contribution to the company's production planning
HR Manager	• Personnel policy • Issues concerning local labor pool • Labor legislation • Communication with other departments and contribution to the company's production planning
Finance Manager	• Availability of financial data concerning the company's production • Communication with other departments and contribution to the company's production planning

The resulting outcome of the production planning assessment was the identification of Company A's opportunities for improvement, which demarked the project's extent – **(3) problem definition**.

The operations director and the PP&C manager validated the results from the assessment, the project's objectives and the models to be developed. In line with Altigan; McCullen (2011)'s recommendation, it was given considerable emphasis to communication throughout the development of the solutions, as early communication gives employees time to absorb, understand and adjust to change.

After defining the project's extent (problem), the project's resulting action plan consisted of developing decision-support models. Therefore, the project's methodology started to entail modelling practices to ensure the proper development of the models.

The phase of **(4) conceptual model development** involved the contemplation of which variables and constrains to include in the models and which assumptions to adopt, in addition to the subsequent development of the models in mathematical/ simulation language. Next, in the **(5) computational model development**, the project contemplated which software programs to use in the development of the computational version of the models – the decision was mainly based upon the software programs' capacity and their accordance with Company A's context.

Then, the project verified the models with the firm's available data to debug them and assess their consistency with the firm's context. Later, the operations director, the PP&C manager and the HR manager validated the models. Such **(6) model verification and validation** took place in numerous sessions through an interactive process that resulted in the refinement of the models' versions. This practice ensured that the models were in line the decision makers' needs and expectations. Moreover, as they participated in the design phase, their resistance to adopt the solutions to which they have contributed will be lower (ALTIGAN; MCCULLEN, 2011).

Finally, as a means to guarantee the models' long-lasting adoption by the company, it was analyzed how their implementation affected the existing production planning in terms of information flows and department's responsibilities and tasks – **(7) implementation analysis**.

4 ASSESSMENT OF THE COMPANY

This chapter presents the assessment of Company A.

Its first section presents an overview about the company’s context and its products.

Its second section contains the description of the production processes for Easter eggs and *panettones*, providing the necessary basis to understand the company’s planning processes (focus of the project).

Its following section, the third one, is dedicated to Company A’s planning processes.

The third section begins by presenting the company’s planning processes through the perspective of the HPP framework, and analyzing each of the its planning modules in-depth. Afterwards, it uses the SIPOC and BPMN diagrams as a means to evaluate the information flows between the planning modules and the role of each department in the production planning process.

At this point, it is important to mention that the decision makers, responsible for planning the Easter eggs production, also plan the *panettones* production. Therefore, the assessment of the production planning of both product categories was conducted in tandem, and is described the same way. As the production of both product categories shows a temporary characteristic, they share many similarities, but the section also highlights the few peculiarities of each one.

Finally, the last section of the chapter addresses all the points of improvement found in Company A’s planning, and presents the project’s action plan.

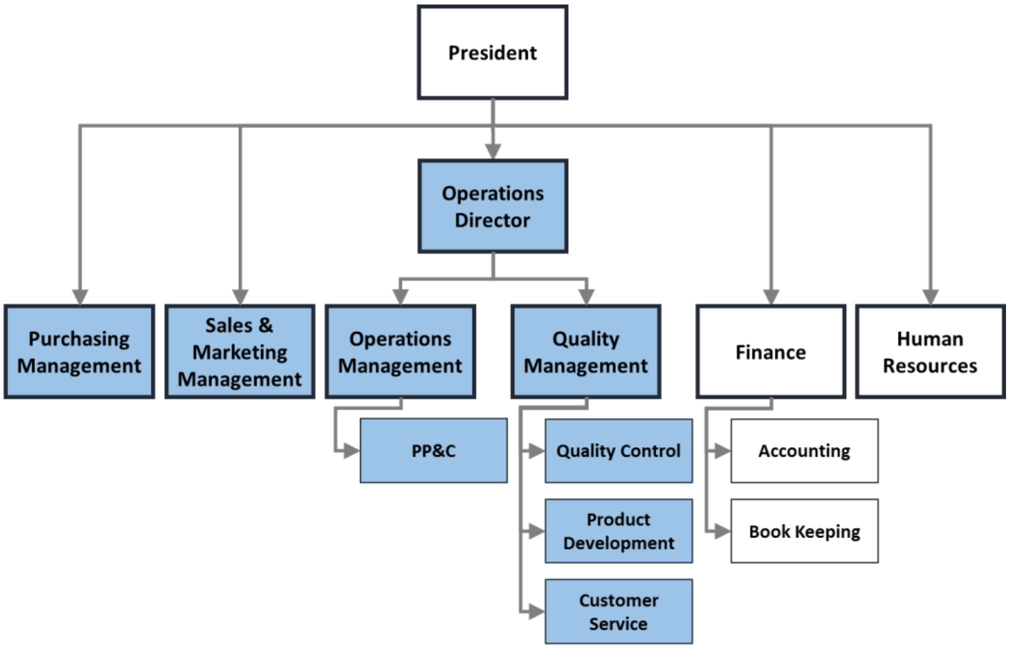
4.1 The Company and The Products

Company A began its operation in 1968 as a bakery, and has grown continually since then, expanding its portfolio from baked goods to its current five industrialized product categories – (1) biscuits, (2) cakes, (3) general chocolate goods, (4) Easter eggs, and (5) *panettones*.

As the expansion took place, the company built an industrial unit to support the high-volume production of its industrialized products. Additionally, in order to improve the management of this industrial unit, the company has created a new brand for these products and assigned a team for the management of this brand and its industrial unit.

Figure 8 presents Company A’ current organizational structure of the business unit related to its industrialized goods. Except from the Finance and the Human Resource departments, which are shared with the bakery business unit, all the other departments (highlighted in the figure) are responsible solely for the business unit of industrialized goods. The president is also the same for both, the bakery and the plant, and oversees both business units.

Figure 8 - Organogram of the Industrial Business Unit



As the company kept growing, the industrial unit's management team implemented the current planning processes and their related decision-support models successively when they felt the need to adopt them.

Since Company A has established agreements with important retailers and contractors, it is aware of the importance of improving and formalizing its implemented production planning processes in order to ensure that it will not lose these agreements due to low service level, and also to maximize profit from them.

On its efforts to enhance its production planning processes, the company expresses a particular concern about the manufacturing of holiday products (Easter eggs and *panettones*) for three reasons. First, due to their seasonal production periods and the more complex planning. Second, due to their relevant participation in the company's profits. Third, due to established agreements with big companies that contract Company A's production capacity (the company does not subcontract the production capacity of its other product categories).

In face of the holiday products' importance to the company, the project focused on the improvement of their planning processes.

4.2 Production Processes

4.2.1 <u>Production Process: Easter Eggs</u>

The production of Easter eggs has its own production area/ floor with two production lines that do not share any machine with neither, nor between themselves nor with the other product categories. The reason for having two lines is that this allows the company to work with milk and white chocolate while reducing setup costs, as the cleansing of the machines when changing from one chocolate type to another is done with chocolate itself. The lines are not exclusive for milk and white chocolate, yet the company schedules the jobs in order to reduce the need for setups.

This production area is active during seven months per year, while it remains inactive (with maintenance activities and equipment installation) during the remaining ones. The active production period of Easter eggs is from August to February.

The manufacturing of Easter eggs is highly automated until packaging. Until this phase, workers are responsible for monitoring the equipment, supplying raw material to each machine, and moving the partly finished products from one phase to another. Concerning the packaging of Easter eggs, it is divided in two phases. In the first one, the workers are responsible for placing candies and toys inside the Easter eggs, and wrapping them in aluminum foil. In the second one, the workers wrap the Easter eggs in plastic sheets, tie them, and stick a brand logo.

The manufacturing process entails six phases, which are the following:

1. **Chocolate Tempering**: Chocolate is stored in tanks kept at approximately 45ºC, and runs through pipes to supply the workstations that have chocolate as one of their inputs. However, the temperature at which the chocolate reaches the workstation is not a proper working temperature (around 30ºC). Hence, the company uses chocolate tempering machines to control the cooling of the received chocolate, and prevent the formation of large crystals inside it;
2. **Chocolate Dripping**: The chocolate-tempering machines supply chocolate to the chocolate-dripping ones through pipes. At this point, these machines are responsible for filling the plastic egg molds according to the size and weight of the future Easter eggs. This phase entails one differentiation point for the Easter eggs produced, as the dripping machine can receive food fragrances (such as strawberry). (At this point, it is important to mention that the differentiation in terms of chocolate results from which tank is supplying the workstation). The plastic egg molds are called "*livros*" ('books' in English), and they vary in the number of cavities they present (for instance, books for 500-gram eggs have less cavities than the ones for 250-gram). They are labelled this way, because the dripping machine just fills the bottom part of the plastic mold and then a worker is responsible for "closing the book" with the top part;

3. **Centrifugation**: After closing the plastic mold with its top part ("closing the book"), the workers attaches them to an industrial centrifuge, which has a certain number of slots. The centrifugation process is responsible for shaping the egg;
4. **Cooling**: The cooling phase is responsible for the full crystallization of the chocolate and is done with an industrial belt cooler;
5. **Packaging I**: In this phase, workers place toys and candies inside the Easter eggs, and wrap them in an aluminum sheet;
6. **Packaging II**: Workers are responsible for wrapping the Easter eggs in plastic sheets, tying them, and sticking a brand logo in this phase.

4.2.2 Production Process: Panettones

Just like the case of the Easter eggs, the product category of *panettones* has a production area dedicated exclusively for it, with a production line that does not share any equipment with the other product categories. As a result, the production line is active during four months per year on average, while it remains idle during the remaining months (it remains active for a month for the production of Easter dove cakes, but the production volume is negligible).

The four active months embrace the period from August to November. During this period, the company produces *panettones*, and distributes them to retail stores and contractors. It is important to observe that the company is not able to produce *panettones* before August due to quality issues – production must be close to the consumption date for the *panettones* to keep their initial softness. In comparison, Easter eggs can be produced a relatively long time before Easter, as their main ingredient, chocolate, can be stored for longer periods without losing quality.

The firm dedicates the idle months to the preventive maintenance of the machines and the installation of additional equipment to increase the production capacity for the following years. The manufacturing process of *panettones* entails nine phases, which are the following:

1. **Preparation of the "*Massa Madre*"**: *Massa Madre* is the initial dough mix that contains mainly water, flour and yeast. It is produced in industrial mixers, and left to rest for 24 hours, so the dough can gain the proper working consistency. In face of the necessity of the 24-hour rest, Company A produces daily batches of the same kind of *panettone* dough – normal or light. This initiative reduces setups between the changes of dough types, even though the setups are minimal, and do not have a significant impact on the production capacity. The setups entail the cleansing of the equipment to eliminate traces of other types of dough;

2. **First "*Empasto*"**: This phase involves the preparation of the "*esponja*" ('sponge' in English), which is the addition of more water, flour and yeast to the dough with the use of industrial mixers. The dough is called "sponge" in this step, because it is ready to absorb food fragrances, and receive fillings after its rest (the next phase);
3. **First Rest**: 10-hour rest in an area with controlled temperature and humidity to allow the yeast to grow;
4. **Second "*Empasto*"**: This phase entails the addition of egg yolk, sugar, malt powder, butter, food fragrance as well as more flour. Besides the addition of these dough components, there is a differentiation point with the addition of chocolate drops and candied fruits. It is possible that nothing is added in this phase, so the *panettone* can receive chocolate or *dulche de leche* filling in the ninth phase. (Note, at this point, the differentiation between *Panettone* with Chocolate Drops versus *Panettone* with Chocolate Filling);
5. **Dough Ball Making**: Company A uses a dough-ball-making machine to automate the process of splitting the dough into smaller quantities, which relate to the future size and weight of the *panettones*. Afterwards, the dough balls are placed manually in paper molds, and acquire their shape during the next phase (the second rest);
6. **Second Rest**: This 10-hour rest takes place in an area with controlled temperature and humidity to allow the dough balls to grow. As they grow, they acquire the shape of the mold and, near the end of this rest, a worker is responsible for cutting the head of the growing dough in the shape of a "X", so it can expand in a centered way outside the mold;
7. **Baking**: This phase consists of baking the dough using an industrial belt oven;
8. **Cooling**: After baking the *panettones*, they are kept in a cooling room for the dough to stabilize;
9. **Packaging**: The packing phase does not only involve the packing of the *panettones*. Before that, this phase begins with the injection of filling in the *panettone*, if it is the case of a *Panettone* with Chocolate or *Dulche de Leche* Filling. Then, all the *panettones* receive a spray bath of chemical preservatives. Their packaging takes place only afterwards.

The labor force practically does not work directly on the dough throughout the process due to its automation with mixers and dough-ball-making machines. This way, workers are responsible for monitoring these machines, supplying raw material to each workstation, and moving the partly finished products from one phase to another.

4.3 Planning Processes

4.3.1 Planning Modules

Table 3 presents the outline of Company A's current production planning.

Table 3 - Outline of the Company's Current Planning Process

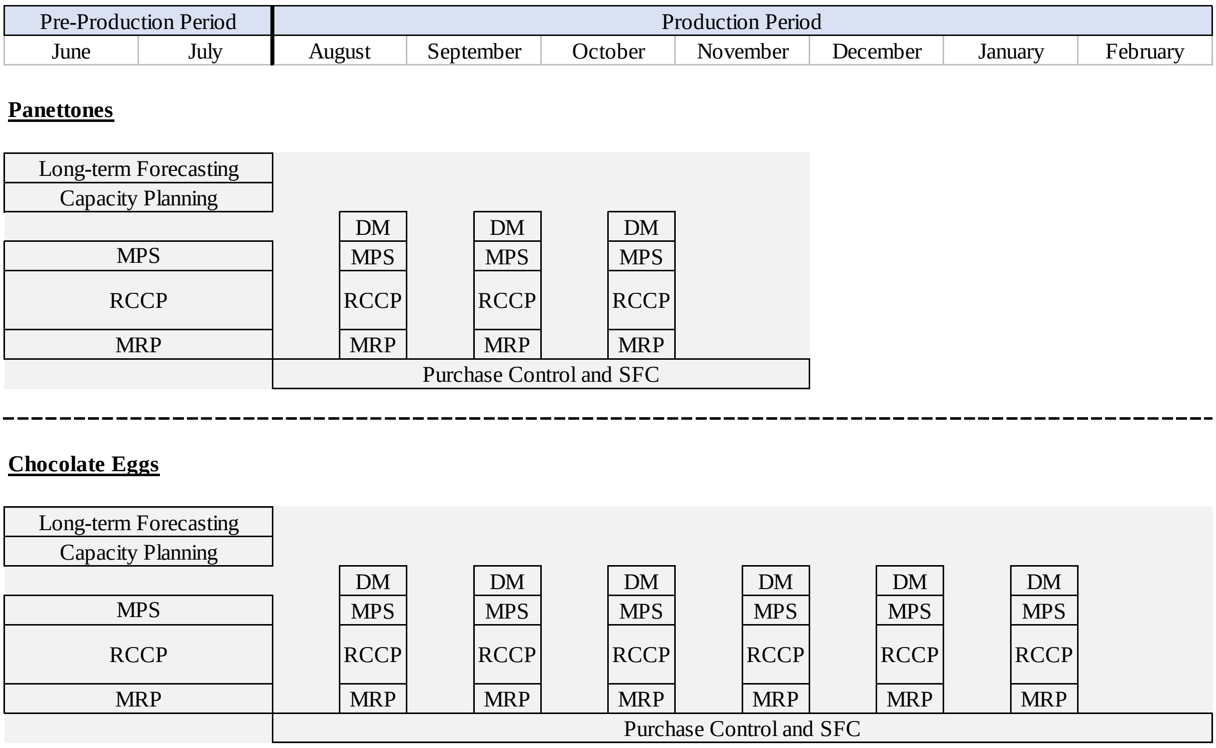
Module	Function	Time Horizon	Revision Frequency
Long-term Forecasting	• Long-term forecasting for each product family • Definition of the sales mix for each product family based on historical data	3 Years	Yearly
Capacity Planning	• Analysis of production lines' capacity to meet the long-term forecasted demand	3 Years	Yearly
Master Production Scheduling	• Disaggregation of the long-term forecast and definition of production levels	Production Period	Every 2 Weeks
Material Requirements Planning	• Determination of material requirements	2 Weeks	Every 2 Weeks
Execution: Shop Floor Control and Purchase Control	• Checking of orders due date fulfillment • Job orders dispatching • Monitoring of the manufacturing system	2 Weeks	Daily
Demand Management	• Updating of demand forecast and the sales mix for each product family according to real client orders	Production Period	Alongside (immediately before) MPS
Rough Cut Capacity Planning	• Validation of the disaggregate plans generated by the MPS	Production Period	Alongside (immediately after) MPS

Regarding Table 3, it is worth mentioning that some of its modules (Master Production Scheduling along with its supporting modules, Demand Management and RCCP) have their time horizon set as “production period” instead of a specific time range (for instance, 3 years, 2 weeks, and so on). This is because the production period for Easter eggs and *panettones* is fixed (seven months and four months, respectively). Therefore, as these modules’ revisions take place during the production time, their time horizon decreases.

Another remark about Table 3 is that it indicates that Company A has some missing modules in its hierarchical production planning: the Aggregate Planning and the Capacity Requirements Planning (CRP).

Figure 9 illustrates the chronology of Company A’s planning.

Figure 9 - Chronology of Company A's Planning Process



*DM: Demand Management

In short, the firm conducts long-term forecasting yearly, prior to the production period, and provides a three-year demand forecast for capacity planning in addition to defining the sales mix that the MPS uses. On its turn, MPS provides the disaggregate demand (validated by the RCCP module) to the MRP system, so it can determine the material requirements for the first weeks of the production period.

After the beginning of the production period, demand management is responsible managing client orders, updating the demand forecast and the sales mix, and providing input for the revision of the MPS. Purchase control checks the fulfillment of the purchase orders’ due dates and supports the management of the company's suppliers base. Shop floor control (SFC) is supposed to take place throughout the production period, but it is inconsistent at the moment.

4.3.1.1 Long-term Forecasting

Each year, Company A conducts a long-term forecasting that covers a three-year period, generally two months prior to the beginning of production of Easter eggs and *panettones* – in June.

In order to improve the forecast accuracy of the first year, the firm conducts a roadshow with its biggest retail clients, who declare a possible volume that they are going to order in that year. Furthermore, this roadshow also involves the company's contractors. However, in the case of contractors, they already stipulate the subcontracting volume in an agreement.

Therefore, Company A's long-term forecast presents the following structure:

- **First year**: This forecast is done with the support of a mathematical model and a roadshow with contractors and retailers;
    - **Contractors**: This part of the long-term forecast is not actually an estimation; it contains the contractors' detailed demand. Two months prior to the beginning of the holiday production period, subcontracting agreements concerning quantities and due dates are established with the contractors. It is worth highlighting that the contractors can make additional orders besides these initial ones during the production period;
    - **Retailers**: Company A performs a roadshow with its main retailers (in terms of sales volume). These retailers state a possible demand, however, they sign no agreement, and these volumes can change as they issue real orders to the company. With the support of a mathematical model, the firm extrapolates the demand to the other retailers. This part of the long-term forecast presents aggregate information concerning the demand;
- **Second and third years**: The firm does this aggregate forecast using a mathematical model with no roadshow involved. This aggregate input is aimed at providing the basis for capacity planning.

It is important to mention that the company uses solely a time series model for demand forecasting, which is also complemented with the inputs from the roadshow. The project hypothesizes that the joint use of a causal model with the existing time series model has the potential of making the company's forecasting more robust.

4.3.1.2 Capacity Planning

The existing production lines undergo recurrent expansion projects, which involve investments in new equipment for them. This capacity planning (and the resulting expansion projects) takes place annually and is based on the company's long-term (3-year) demand forecast.

Company A already has a decision-support model to assess the trade-off between 'operational performance vs cost' of its expansion projects. Nevertheless, there is no model that supports the design and balancing of the expansion alternatives and that allows the company to predict the operational performance derived from the new equipment investments. Therefore, the operational performance used in the trade-off analysis limits the assessment of the expansion projects.

In the current capacity planning, Company A visually identifies the production bottlenecks, with no meticulous analysis of the cycle times of each workstation. Then, it compares the nominal capacity of the machine(s) in the identified bottleneck workstation with the three-year forecast and the cycle time of the entire production line. Through this comparison, the company defines which additional equipment to purchase.

This approach has a serious limitation: the effect of a moving bottleneck. After the definition of which equipment to add in the bottleneck, the company does not analyze which workstation will be the next bottleneck. Therefore, the new equipment purchase may not be sufficient to provide the expected operational performance due to this new future bottleneck. For instance, the addition of a new equipment in the current bottleneck is expected to provide an increase of 30% in the production line's capacity. Yet, after the addition of the equipment, another workstation will be the bottleneck, and may constrain the capacity increase to 15%.

It is worth mentioning that the company's control system that monitors the production is still nascent. Yet, it already provides the production time of each workstation, allowing the company to predict the future operational performance and bottlenecks of a line expansion.

Therefore, the company is already in condition to implement a model that supports the assessment of the expansion alternatives' operational performance and that provides an accurate input for the trade-off analysis between 'operational performance vs cost'.

Moreover, the production of Easter eggs has two workstations, whose production rate depends on the number of employees, as they work directly on the products, placing candies and toys inside the Easter eggs, and wrapping them in aluminum foil and plastic sheets. In this case, the company empirically allocates a number of employees for these workstations.

The definition of such number can also be supported by the implementation of the same type of model, allowing the balancing of the workstations' resources (machines and workers) through the indication of their operational performance.

4.3.1.3 Workforce Planning

Company A has a well-defined personnel policy for the manufacturing of its holiday-related products, which is in line with the alternated running of its production lines between active production periods (seven months for Easter eggs and four months, for *panettones*) and extensive idle periods.

The firm uses only temporary workers for the production of both product categories in order to avoid a costly and idle permanent workforce when outside of the holiday production period. Therefore, each year the firm hires temporary workers before and during the production period, with a pre-determined contract that, according to the Brazilian legislation, specifies their start and end dates, their shift and the possible amount of overtime hours they will work.

Despite the well-defined personnel policy, Company A has an unclear personnel/ staffing plan concerning when and how much workers to hire/ fire, their shifts, and their possible amount of overtime. Since the beginning of the company's operations, it adopts the same staffing plan with some little modifications from year to year. However, no formal model/ methodology supports such a decision. The decision is based on the company's empirical knowledge.

Currently, the company faces the following problems regarding its temporary workforce:

- Since the contracts with the temporary workers are supported by an unclear staffing plan, the company sometimes does not respect their pre-determined conditions, and, for instance, lay workers off before the established end date. In these cases, the company incurs a penalty for breaking the contracts, and distresses the workers (some of them do not even apply in the following years);
- Company A tends to adjust its staffing plan during production time (for instance, by using a third shift and overtime), as soon as it starts to have problems coping with the demand. This approach gives the company little reaction time and flexibility, and jeopardizes its service level.

As there is the possibility of adding workforce-related variables to production-planning models, the firm can decide upon its staffing plan during aggregate planning.

4.3.1.4 Aggregate Planning

Company A skips this module in its planning process.

The module's adoption has the potential of lowering considerably the firm's production costs, and even increasing its service level due to the following reasons:

- Company A does not have a decision-support model to define a staffing plan in a systematic and formal way. Aggregate planning is able to support the setting of this plan, reducing the labor fines that the company incurs, motivating its workers, and properly sizing extra hours to enable workers' availability when the firm needs them to work overtime;
- The firm does not have a tool to support the negotiation with neither the contractors nor the retailers. Lately, the company has faced some issues when trying to meet these agreements, especially with the contractors. Moreover, when trying to meet these agreements with contractors, the company has jeopardized part of the production of its own brand to retailers. Aggregate planning can support the negotiation of quantities and due dates with contractors and retailers, and set production and inventory goals, so that the company can also satisfy the demand for the products of its own brand;
- Aggregate planning supports the setting of workforce allocation, as well as production and inventory levels, in a way that the main production parameters are considered, and the plan minimizes production cost (or maximizes profit).

4.3.1.5 Master Production Scheduling (MPS)

Company A uses a model to disaggregate the first-year demand provided by the long-term forecasting. As discussed earlier, the first year of the long-term forecast presents the (1) actual and detailed demand from contractors, and the (2) estimated and aggregate demand from retailers. Thus, the model works on the (2) estimated and aggregate demand from retailers.

Afterwards, the firm defines the production levels in addition to validating them with the consideration of capacity constraints (RCCP).

It is important to highlight two current issues in the RCCP module.

First, the PP&C manager, who is responsible for running the RCCP module, usually sets the manufacturing system's capacity according to an unclear staffing plan based on his empirical knowledge (in terms of which production shifts to use, how many regular hours and overtime hours to use, and so on). Therefore, the outcome from the module is far from being the most advantageous for the company in financial terms.

Second, as discussed in the subsection devoted to capacity planning, Company A finds out the cycle time of each production line just when these lines are running, once it does not have a model to support the balancing of the production lines and the analysis of their cycle times/

bottlenecks. Because of this, when a production line has just been shifted/ expanded, the capacity employed in the RCCP is lagged and inaccurate.

4.3.1.6 Material Requirements Planning (MRP)

Company A makes use of a MRP system to determine the material requirements.

The implementation of this system was one of the key points of the company's past initiatives to enhance its production planning. Nevertheless, there is no CRP module to support the launch of orders to the manufacturing system. That is, there is no capacity-ensuring module to analyze if the orders generated by the MRP are feasible in practice, which jeopardizes the company's service level. The company currently checks whether the job orders are respecting their due dates, and tries to correct any disparity with overtime work.

As Hopp; Spearman (2008) and Harrison; Petty (2002) state, the implementation of the CRP requires a detailed and accurate feedback from the SFC module, which is still nascent in the company and, thus, hinders the implementation of the CRP.

The following subsection discusses the execution control modules – purchase control and SFC –, and highlights their points of improvement.

4.3.1.7 Execution: Purchase Control and Shop Floor Control

The firm currently checks whether the jobs and purchasing orders are in accordance with their due dates.

Still, the operations department has little visibility over the entire manufacturing system, as the monitoring of the running conditions, such as WIP level, is still emerging. Currently, there is an employee, who is responsible for creating control reports, but his job description is not well defined in terms responsibilities, span of control, timing, and the like. Besides that, this employee has other responsibilities, and usually leaves the monitoring aside, conducting it in an irregular basis.

A proper visibility over the system's running would enable the implementation of the CRP, and would provide robust inputs for running the high-hierarchy modules.

The company recognizes the importance of having a clearer view over what is happening in the shop floor, and expressed that it is studying ways to improve the control system.

4.3.2 Information Flow

The project employed the process-mapping tools SIPOC and BPMN in order to assess the company's current information flow in its production planning processes.

The employment of the SIPOC diagrams aimed at evaluating how the company allocates the planning modules among its departments, and how these departments communicate with each other. With the results from the SIPOC diagrams, the project employed the BPMN diagram in order to obtain an outline of the coordination of the planning-related information flow between the departments. APPENDIX A – DIAGRAMS FOR COMPANY A'S CURRENT INFORMATION FLOW contains the resulting diagrams of this assessment.

The process of mapping the planning modules, their related information flows and their participants allowed the project to identify two main issues in Company A's planning.

First, throughout the mapping process, the project could observe that there is room for improvement in the communication among departments, as the information flow is done via email, and even hardcopy reports. Such information management is subject to typing errors when transferring data from one document to another, and it allows different versions of the same data. The integration of the departments' systems has the potential of greatly benefiting the company by consolidating its database, and providing such data to all departments in an updated and timely manner.

The second issue concerns the participation of the HR department in the production planning. This department is not involved directly in the planning, despite the fact that it can greatly contribute to the definition of a formal staffing plan.

4.4 Diagnosis and Action Plan

Table 4 summarizes the points of improvement that the project observed according to the perspective of the HPP framework.

Table 4 - Outline of the Company’s Opportunities for Improvement

Planning Module	**Observed Strengths**	**Points of Improvement**
Long-term Forecasting	• Aggregate approach towards long-term forecasting • Roadshow to enhance forecasting accuracy	• Complementary use of a causal model may make the forecasting process more robust
Capacity Planning	• Use of long-term demand forecast as input for capacity planning • Model to assess the trade-off between operational performance and cost	• Lack of a decision-support model to guide the design and balance of expansion alternatives for the production lines, and to assess their operational performance
Workforce Planning	• Personnel policy of using temporary workforce aligned with the company’s context	• Staffing plan is not defined in a formal and systematic way
Aggregate Planning	(It is not performed)	• Lack of a production-planning model to support production, inventory and workforce allocation
Master Production Scheduling	• Consideration of the historical demand mix and the new orders by the disaggregation model • Assessment of the generated plans’ feasibility	• Feasibility assessment is hindered by lagged capacity inputs and lack of well-defined staffing plan
Material Requirements Planning	• Use of MRP to determine material requirements	• No capacity evaluation on the generated orders
Production Execution & Control	• Proper checking of due dates fulfillment	• Inconstant and fuzzy monitoring over the conditions of the manufacturing system

By mapping the planning modules along with their related information flows and participants, the project could also observe the following points of improvement:

- Lack of IT integration among the departments in order to prevent inconsistent data over the company, and to provide each department with updated and timely data;
- No participation of the HR department in the company's production planning.

In order to address the identified points of improvement, the project aimed at developing a **(1) Line-Balancing Model** and a **(2) Production-Planning Model**.

With respect to the **line-balancing model**, the project expects its implementation to:

- Support the process of designing and balancing the configuration alternatives of the production lines' expansion/ shift in capacity, by allowing the company to predict the operational performance of the alternatives;
- Provide accurate input about the alternatives' operational performance in order for the company to properly assess the trade-off between 'operational performance vs cost' of each one of them;
- Assist the balancing of the number of workers per shift and production line for the packaging workstations of Easter eggs;
- Provide the subsequent (lower-hierarchy) planning modules with robust and unlagged inputs about the production lines, especially their production times. This is especially important to ensure a proper running of the aggregate and the MPS/ RCCP modules.

The running of this model needs data about the shop floor, as it needs the production time of each workstation. Despite its nascent state, the company's control system is currently able to feed the model with such inputs, and does not hinder its implementation. However, more precise and updated data about the shop floor certainly contributes to the robustness of the company's planning. Thus, the project stresses the importance of the company's current endeavor in enhancing the current control system.

With regard to the **production-planning model**, the project expects its adoption to:

- Support the definition of a formal staffing plan (in terms of when and how much workers to hire/ fire, their shifts, and their possible amount of overtime) before the beginning of each production period, and incite the participation of the HR department in this process;
- Establish a cost-aware perspective in the high-hierarchy modules by setting production, inventory, and workforce levels with the contemplation of the related

costs. Such perspective incites a more active participation of the financial and purchasing departments in the company's planning process;

- Deliver robust inputs for the running of the succeeding planning modules. This is the case of the MPS module alongside its validation by the RCCP module, which currently need a proper (clear and cost-aware) staffing plan.

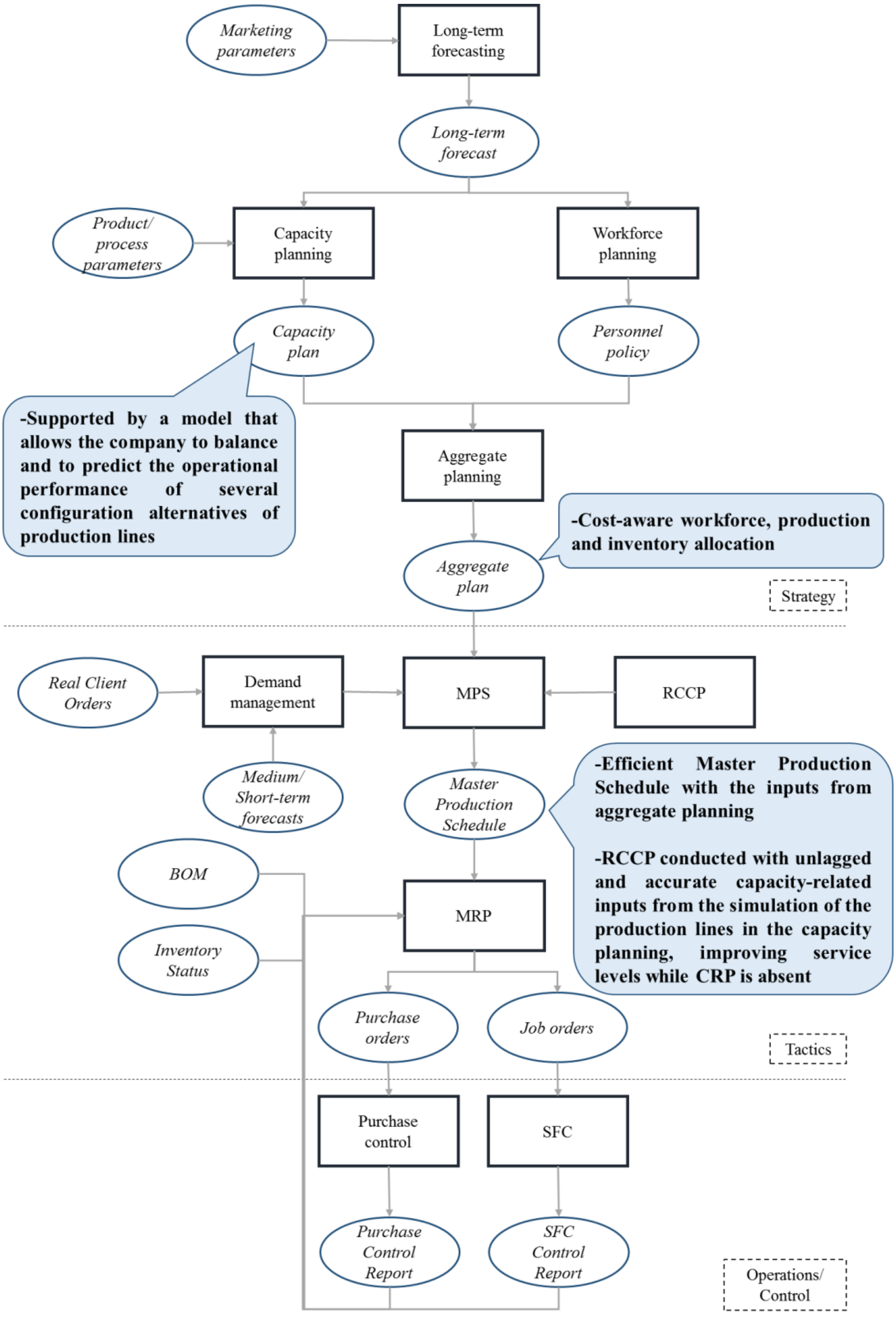
Figure 10 highlights the expected results from the implementation of these two models.

As the project could not address all the identified opportunities for improvement, it focused on the points that could bring more benefits to Company A, and that could drive a more structured decision-making process within the firm. For this reason, the project did not focus on the development of a causal forecasting model, nor on the implementation of an IT system to integrate the information flows among departments. However, the project acknowledged their importance, and strongly recommended the company to address them.

As the project aimed at the long-lasting adoption of the developed models, during their development, it considered the following points as critical success factors:

- **Engagement by the end user**: Co-creational process through validation sessions with the decision makers to ensure that the models are in line with their needs;
- **Presence of a project leader ("champion")**: Engagement of one employee throughout the development of the project in order for him to have responsibility over the implementation and adoption of the models. In the case of Company A, such employee is the PP&C manager, who is also the model's end user;
- **Consideration of the company's current state**: Attention to the company's as-is situation in terms of the adopted software, the participating departments and data availability;
- **Assessment of the implementation of the models**: Evaluation of how the developed models will affect the company's current production planning and how to guarantee their adoption;
- **Support from top management**: Endorsement by the top management through the allocation of resources to the implementation of the models. The project aimed at engaging Company A's top management (its president and operations director) in the development of the models in order for them to perceive the relevant decision variables that the models provide to support production planning.

Figure 10 - Expected Results from the Implementation of the Models



Impact on the company:

-More efficient tactical and operational planning and execution, based on the inputs from aggregate planning
-More robust RCCP and consequent master production schedules, which improves service levels while CRP is absent
-Reinforcement of an formal approach towards production planning and acceleration of the company's current endeavor of enhancing SFC and implementing CRP

5 LINE-BALANCING MODEL

This chapter presents the line-balancing model developed for Company A.

Since there are differences between the production processes of Easter eggs and *panettones*, its first section explains the line-balancing model according to the peculiarities of the Easter eggs production, while its second section explains the model in accordance with the *panettones* production.

5.1 Line-Balancing Model for Easter Eggs

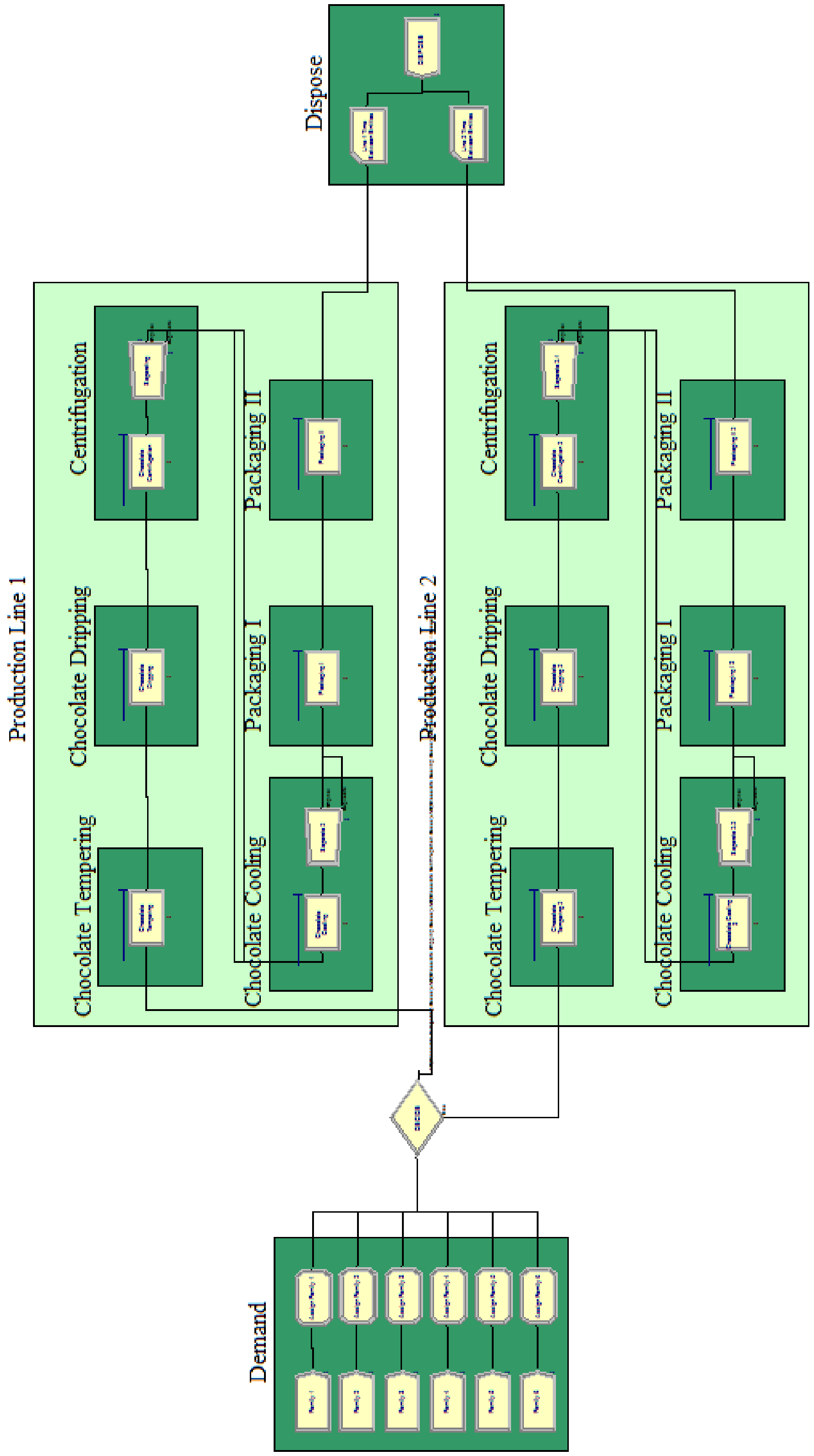
As reported earlier, Company A already has a decision-support model that financially assesses the trade-off between 'operational performance vs cost' derived from shifts in production lines (for instance, investment in new equipment) during its annual capacity planning. Nevertheless, there is no model that supports the design and balancing of the capacity-shift alternatives and that allows the company to predict the lines' operational performance. Consequently, the trade-off analysis is jeopardized by the input related to the operational performance.

For this reason, the project chose to develop a simulation model that reproduces the company's existing production lines, and supports their yearly rebalancing/ shift. As its main outputs, the developed model indicates the production bottlenecks that hinder the lines' operational performance, and provides the lines' cycle time/ production capacity (the operational input necessary for the company's financial model).

The line-balancing model was developed in the software Arena by Rockwell Automation due to its powerful simulation capacity, and is presented in Figure 11.

In order to better explain the developed model, its rationale is broken down into logical building blocks, which reproduce the Easter eggs production: (1) jobs generation, (2) workstation representation, (3) production flow, and (4) disposal of the simulation entities. These building blocks and their underlying assumptions are now explained in-depth.

Figure 11 - Line-Balancing Model for Easter Eggs



Jobs generation

In order to facilitate the explanation, this report begins by explaining the rational for one product family, and then expands it to a general explanation for several product families.

In the developed model, the block *CREATE* generates entities in constant time intervals, which represent the job order for a batch of a specific product family.

The underlying assumption here is that the demand is distributed equally throughout the simulation period in order to analyze the production line's operational performance without the interference of an uneven demand pattern. (The developed production-planning model is the one that deals with the lines' operational performance in face of an uneven demand pattern, and chooses which production strategy to follow – 'chase vs level vs hybrid').

In order to equally distribute the demand throughout the simulation period, the project proposes the following:

1. As the company's long-term forecasts embrace three years, the demand level to analyze is the maximum total demand among the three years;
2. Since the demand level is given in units, it must be converted to batches;
3. This maximum total demand is distributed according to the total available production time.

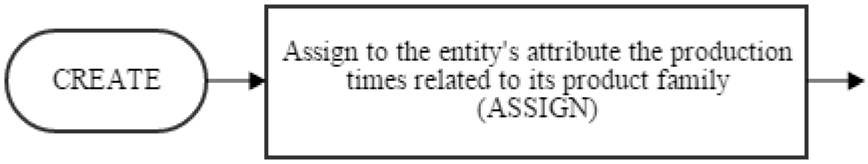
For instance, the maximum total demand for the Easter egg product families is at the third forecasted year, and accounts for 100 batches. The theoretical available production time for the third year accounts for 500 hours throughout the seven-month production period dedicated to Easter eggs. Thus, the entities are generated at 0.2 entities per hour, and the Arena's simulation run time is set at 500 hours. (These are all hypothetical numbers).

It is worth highlighting that the conversion from units to batches follows the centrifuge's slot capacity, which is 28 "*livros*" for the company's equipment.

Another two important assumptions that are considered in this building block is that (1) the production times vary according to the product families as well as the resources used in their production, and that (2) the production times have a triangular distribution (assumption is in line with the company's data).

In order to implement these two assumptions, the model adopts the block *ASSIGN*, which creates attributes within the generated entities, and assigns values to these attributes. Figure 12 illustrates the rationale.

Figure 12 - Conceptual Model: Demand Generation



Since the production times have a triangular distribution, and they vary according to the resources used in the production of the product families, the **attributes** to be created are the following:

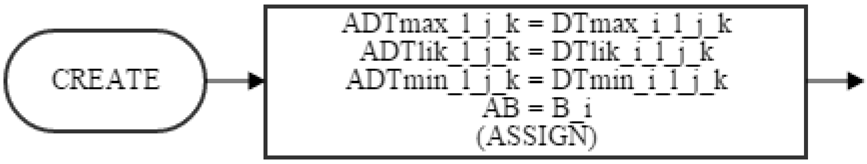
$ADTmax_{ljk}$ = Attribute related to the maximum production time (delay time in Arena's language) of resource k at workstation j in production line l
$ADTlik_{ljk}$ = Attribute related to the most likely production/ delay time of resource k at workstation j in production line l
$ADTmin_{ljk}$ = Attribute related to the minimum production/ delay time of resource k of workstation j in production line l

As show in Figure 13, these attributes receive their corresponding values through the **variables** $DTmax_{iljk}$, $DTlik_{iljk}$ and $DTmin_{iljk}$.

$DTmax_{iljk}$ = Maximum production/ delay time of product family i by resource k of workstation j in production line l
$DTlik_{iljk}$ = Most likely production/ delay time of product family i by resource k of workstation j in production line l
$DTmin_{iljk}$ = Minimum production/ delay time of product family i by resource k of workstation j in production line l

Another **attribute** that the entities receive is AB, which is associated with the **variable** B_i. This attribute is explained later on. For now, its explanation is not relevant.
It is worth mentioning that the project assigns variables instead of pure values to the attributes, because the Arena software contains a spreadsheet that links variables to their values. Therefore, this approach simplifies the update of values throughout the model's long-lasting adoption by Company A.

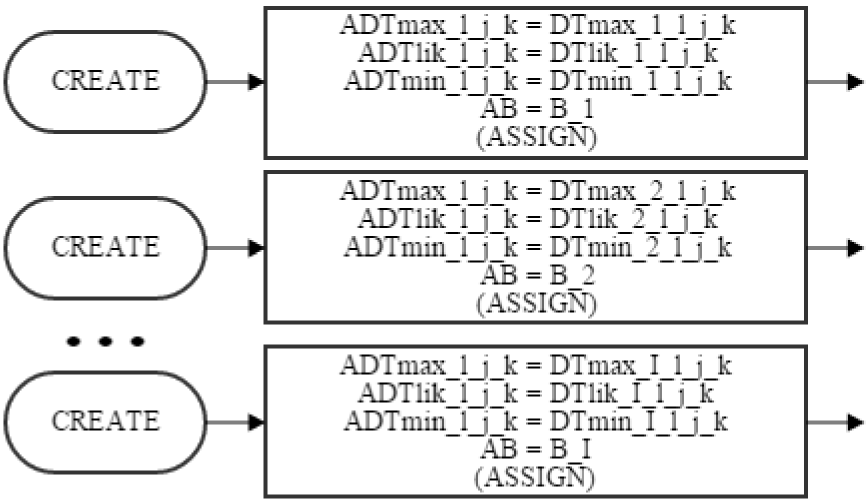
Figure 13 - Computational Model: Demand Generation



The block *PROCESS* recovers these attributes and their respective values later (explained in the rationale behind the representation of the workstations).

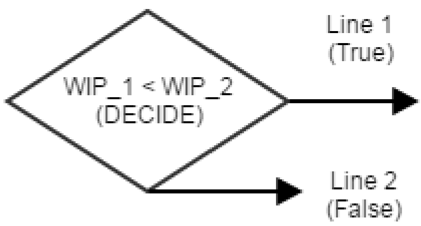
It is important to notice that the rationale explained so far involves just one product family. To include other families, the computational model in Figure 13 is replicated to each product family, resulting in the scenario illustrated in Figure 14.

Figure 14 - Computational Model: Demand Generation for Several Families



It is also important to remind that the Easter eggs production has two lines. Therefore, an additional block, the *DECIDE*, is implemented in order to allocate the generated entities according to the production lines' WIP (Figure 15).

Figure 15 - Computational Model: Allocation to Production Lines



In addition to the block *DECIDE*, two blocks *ASSIGN* are placed in the beginning and in the end of each production line in order to track the production lines' WIP and provide the necessary information for the block *DECIDE*.

By observing the model presented in Figure 11, it can be perceived that the model does not have the above-mentioned blocks *ASSIGN*. This is because the model was developed in the

Arena's student version, which limits the number of flowchart blocks. Thus, the Figure 11's *DECIDE* allocates the entities according to the production lines' current number of entities in queue in order not to exceed the number of flowchart blocks allowed in the student version.

Workstation representation

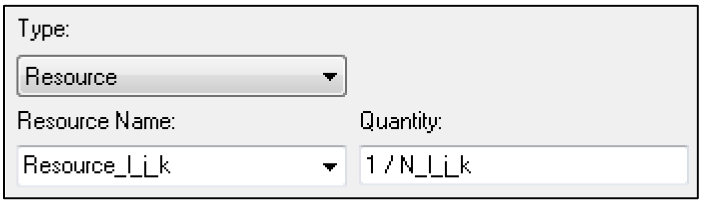
In the developed model, the block *PROCESS* is used in order to represent the workstations. As the software Arena requires at least one resource to be associated to the block, the project adopted the following assumption: "the resource that represents a production process is the one that directly affects the process's production rate".

For instance, the manufacturing of Easter eggs is highly automated until packaging. Until then, workers are solely responsible for monitoring the equipment, supplying raw material to each machine, and moving the partly finished products from one phase to another. Therefore, even though a workstation (e.g. chocolate dripping) has more than one resource (the chocolate-dripping machine and the monitoring worker), its production rate is closely correlated to one of them (the chocolate-dripping machine). This is the case of the following workstations: Chocolate Tempering, Chocolate Dripping, Centrifugation and Cooling.

In the case of the packaging of the Easter eggs, the number of workers is directly correlated to the workstations' production rate. Thus, the block *PROCESS* is associated with the resource 'worker' instead of 'equipment'.

As Figure 16 presents, when a resource is allocated to the block *PROCESS*, its quantity needs to be determined. The project proposes to use this value as $1/N_{ljk}$, where the **variable** N_{ljk} represents the number of resources k at workstation j in production line l.

Figure 16 - Arena's Process Block: Configuration of the Resource



This approach allows the simulation model to consider the parallel effect of resources of the same type in the workstation, without the need for replicating the block *PROCESS* for each one of the identical resources. For instance, Company A has two identical chocolate-dripping machines in a production line. In order to represent these machines, the simulation model just requires one blocks *PROCESS* rather than two.

Regarding the number of resources, N_{ljk}, it is important to observe how this variable supports the balance of the workforce level required in the workstations Packaging I and Packaging II, which, as mentioned before, are represented by the resource 'worker'. Through the simulation of different scenarios, the user is able to set properly the number of workers in order for them not to be the production lines' bottlenecks.

As Hopp; Spearman (2008) states, flow lines tend to be unbalanced for two reasons. First, the cost of capacity is typically not the same at each station, making it cheaper to maintain excess capacity at some workstations. Second, capacity is usually available in discrete-size increments, and it is sometimes impossible to match the capacity of a certain station to a particular target. Therefore, until the packaging of Easter eggs, it is common not to have a perfectly balanced line. However, a process with small and inexpensive increments – such as the case of the packaging of Easter eggs – should never be a bottleneck to the rest of the flow line.

Therefore, in the case of Easter eggs, the line-balancing model supports the decision makers to balance both line's resources properly – equipment and workers –, being in line with Hopp; Spearman (2008)'s recommendation.

It is worth emphasizing that Company A's workstations all have identical resources. Therefore, the approach with the **variable** N_{ljk} to address their parallel effect (by representing their quantity as$1/N_{ljk}$) is sufficient. Nevertheless, if the company wants to evaluate the addition of another resource type (for instance, the company has just type-A centrifuges, and it wants to invest in type-B centrifuges), an adjustment of the approach is required. The project developed such adjustment in the case it is needed in the company's future capacity planning. APPENDIX C – LINE-BALANCING MODEL: RATIONALE FOR DIFFERENT RESOURCES AT THE SAME WORKSTATION describes it.

Regarding the block *PROCESS*, it also important to observe that it retrieves the entities' attributes (consequently, their respective values) as shown in Figure 17.

Figure 17 - Arena's Process Block: Configuration of the Delay

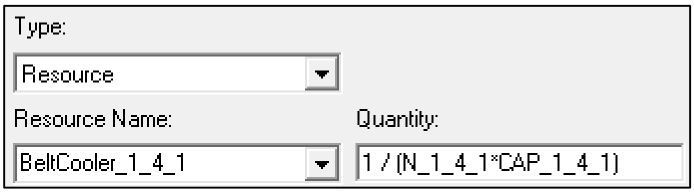
As it can be observed from the explanation of this building block, it has the following assumptions:

1. Setups are not considered, as the firm neglects them, not even monitoring them;

2. The simulation model does not embrace production-related costs, as the production-planning model deals with this issue. The major financial decision driver in Company A's capacity planning is the equipment purchase cost, which is already considered in the company's economic-engineering model;
3. Machines do not break down during the production period, because Company A dedicates the plant's idle months for the preventive maintenance of equipment. In addition, it conducts some ramp-up tests prior to the production period in order to ensure no breakdowns.

An important remark must be made in relation the cooling process of Easter eggs, which has an additional **variable**, CAP_{ljk}, in its representation by the block *PROCESS*. Such **variable,** CAP_{ljk}, represents the maximum capacity that the belt cooler (resource k) at workstation j in production line l can hold/ work concomitantly. Figure 18 shows how the quantity of resources of the cooling process is determined in the block *PROCESS*.

Figure 18 - Arena's Process Block for the Cooling of Easter Eggs

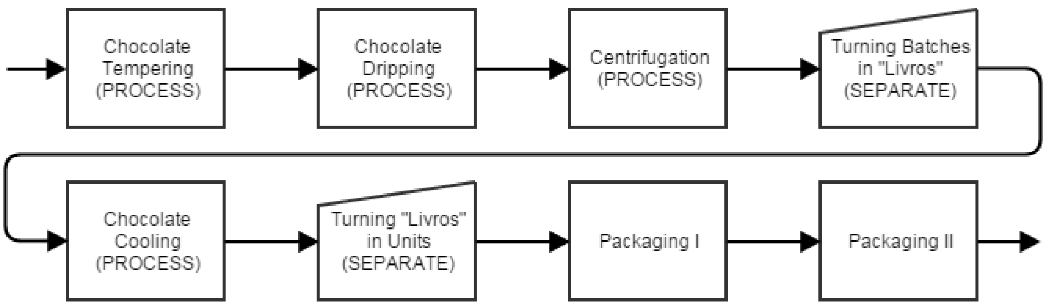


Production flow

As described previously, the manufacturing of Easter eggs entails the following phases: (1) Chocolate Tempering, (2) Chocolate Dripping, (3) Centrifugation, (4) Cooling, (5) Packaging I, and (6) Packaging II.

In order to reproduce the manufacturing process, each one of the phases' workstations was represented by the block *PROCESS*, as explained previously. In addition, two blocks *SEPARATE* were included in the production flow, as Figure 19 shows.

Figure 19 - Conceptual Model: Easter Eggs Production Flow



Since jobs are generated in the block *CREATE* in terms of batches, these batches are later broken down into units/ items as the entities run through the production flow. This way, the two blocks *SEPARATE* are responsible respectively for turning the production batches in "*livros*" and, afterwards, the "*livros*" in units.

The computational setting of the blocks *SEPARATE* is quite easy, because the decision maker just needs to set the amount of duplicated entities to be generated.

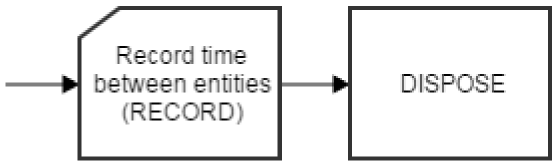
The first block generates 28 entities (the original plus its 27 duplicates), as all of the company's current centrifuges have this capacity.

The second block retrieves the entities' **attribute** AB, and consequently, generates $B_i - 1$ entities, where B_i is the amount of Easter eggs in one "*livro*" ('book'). It is worth remembering that the amount of Easter eggs that a "*livro*" holds depends on their size.

Disposal of simulation entities

As Figure 20 shows, the disposal of the simulation entities is simply done with the block *DISPOSE*. Prior to this block, the project uses the block *RECORD* to compute the production line's cycle time (an indicative of its production capacity), which the company needs to run its financial model for capacity planning.

Figure 20 - Conceptual Model: Disposal of Simulation Elements



Furthermore, the Arena also automatically reports, among other relevant decision variables, the resources' utilization rate, queue sizes and waiting times. By providing such information, the decision maker is able to determine the bottleneck of the production line (the workstation with the longest waiting time and the highest resource utilization rate).

It is worth noticing that the simulation model is able to provide robust inputs to the aggregate planning and RCCP modules. By simulating the production of each product family and product item individually (without any other product items or families being generated), the model provides the cycle time of the specify item or family, and feeds production-planning and the RCCP models.

For instance, in the case of the production-planning model (explained in the next chapter), the line-balancing model is able to provide the production lines' cycle time and also assist in the definition of the required number of workers per production line and shift for the production-planning model to set properly the production, inventory and workforce levels.

At this point, it is important to highlight that the line-balancing model supports the company to set the number of workers in the packaging workstations of Easter eggs (the production of this product category involves more workers who are responsible for equipment monitoring as well as the handling of raw material, WIP products and finished products). Therefore, it assists the definition of the number of workers per shift required to run a production line. The production-planning model deals with a different aspect of the workforce. It considers the required number of workers per production and shift as well as the related labor costs in order to set the workforce level in terms of the use of production shifts, the use of regular and overtime hours, and the timing of hires and layoffs.

5.1.1 Verification of the Model

As mentioned earlier, the line-balancing model was developed in the software Arena, which offers full functionality in its student version for **building** and **executing** training-size models. With respect to **building** the model, the software's student version proved to be sufficient to represent one production line in terms of flowchart blocks and variables, since the manufacturing of Easter eggs is not too complex in terms of its related phases and resources. However, the addition of the second production line exceed the number of variables allowed in the student version.

About **executing** the line-balancing model, the student version constrains the number of simulation entities running simultaneously in the model. Thus, such a limitation did not allow the model to run with the company's data and reproduce its current functioning.

Since the beginning of the development of the line-balancing model, the project was aware of this issue, yet the project intended to avoid it with the support of the *Escola Politécnica da USP*'s laboratory, which had the software's commercial version. However, the laboratory's license expired, and it was not renewed in time for the project to run the full-size model with the company's data.

This situation points out a relevant limitation for solutions that involve simulation: their high dependence on paid software. There are free simulation software programs, yet their limited simulation capacity and features require the models to be too simple in a way that the assessment of a real-world manufacturing system is jeopardized. This was the case of the free software Bizagi, which the project tried to use prior to the Arena.

Due to this unforeseen incident, the verification of the model was hindered, and project could only assess the model's running with one batch of the product family 3/ 6 (they have the same manufacturing characteristics) in one production line. Since the other families are related to smaller Easter eggs, they present a higher number Easter eggs per batch, which exceeds the execution limitation of the Arena's student version.

For the simulation run with one batch of product family 3/ 6, the project compared the production line's cycle time obtained in the model with the one provided by the company (which was used in the production-planning model). With such verification, the project could identify possible errors and inconsistencies in the model, and evaluate the model's capacity to reproduce the company's current situation.

Table 5 present the result from the verification test, which used the data contained in the APPENDIX B – DATA FROM COMPANY A.

Table 5 - Result from the Verification of the Line-Balancing Model for Easter Eggs

Product Family	**Cycle Time provided by Company A**	**Cycle Time obtained in the Model**
F3 and F6	1,58 Seconds/ Easter Egg	1,63 Seconds/ Easter Egg

5.1.2 <u>Validation of the Model</u>

The project validated the model with the operations director, the current decision maker regarding the expansion of the productions lines, and the PP&C manager, the responsible for running the model once it is implemented in the company. After its validation, the model was also presented to the company's president in order to obtain his support for the implementation of the model.

The president and the operations director appreciated the model's descriptive nature and showed interest in the insights that the model can generate when simulating diverse alternatives of manufacturing configurations/ equipment purchase. On his turn, the PP&C manager did not perceive the underlying logic of the Arena as difficult, and understood the developed building blocks.

It is important to highlight that the building and execution of a full-size model was not possible due to the limitation of the Arena's student version. Therefore, the project just presented the above-mentioned verification test and some other examples with meaningless numbers to show the model's functioning, and to discuss how it would impact the company's production planning.

In the presentation/ discussion, the models' impact was reinforced with emphasis on its support to the systematic identification of production bottlenecks and the assessment of the lines' operational performance. Nevertheless, the speech about the model's benefits was hindered by the lack of a full-running model.

With the commercial version, the project aimed at performing a second series of verification tests to evaluate the company's expected bottlenecks in face of its long-term (3-year) forecasted situation. This series of verification tests would be used as the basis for the speech in favor of the implementation of the model.

Despite such stumbling block, the president and the operations director expressed that they will discuss the implementation of the model for the next year (2016).

5.2 Line-Balancing Model for Panettones

In order to avoid redundancies, this section focuses on indicating how the differences between the manufacturing of Easter eggs and *panettones* reflect on the model presented on the previous section (dedicated to Easter eggs).

The resulting line-balancing model for *panettones* is shown in Figure 21.

As in the previous section, the modelling rationale is broken down into logical building blocks to explain the model better: (1) jobs generation, (2) workstation representation, (3) production flow, and (4) disposal of simulation entities.

Jobs generation

Just like the developed model for Easter eggs, the model for *panettones* uses the block *CREATE* to generate entities in constant time intervals, which initially represent the job orders for a batch of a specific product family.

The 'jobs generation' building block for *panettones* also follows the same assumptions considered for Easter eggs: (1) demand is equally distributed throughout the simulation; (2) the production times vary according to the product families and the resources used; and (3) the production times have a triangular distribution.

In addition, it adopts the same **attributes** ($ADTmax_{jk}$, $ADTlik_{jk}$ and $ADTmin_{jk}$) and **variables** ($DTmax_{ijk}$, $DTlik_{ijk}$ and $DTmin_{ijk}$) to deal with the triangular production times of each product family in each workstation and respective resource.

With regard to the **attribute** AB and its related **variable** B_i, they are also adopted with the same purpose and meaning: indicate for the block *SEPARATE* the quantity of units (in the case of *panettones*, dough balls) that a batch generates.

It is also important to remind that the manufacturing of *panettones* has just one production line. Therefore, the additional block *DECIDE*, implemented in the case of Easter eggs, is not needed.

Workstation representation

After the preparation of the "*massa madre*", the production of *panettones* entails the following phases: (1) First "*Empasto*", (2) First Rest, (3) Second "*Empasto*", (4) Dough Ball Making, (5) Second Rest, (6) Baking, (7) Cooling, and (8) Packaging.

For the representation of the workstations of each phase, the project used the block *PROCESS* with the same assumption adopted in the case of Easter eggs – "the resource that represents a production process is the one that directly affects the process's production rate".

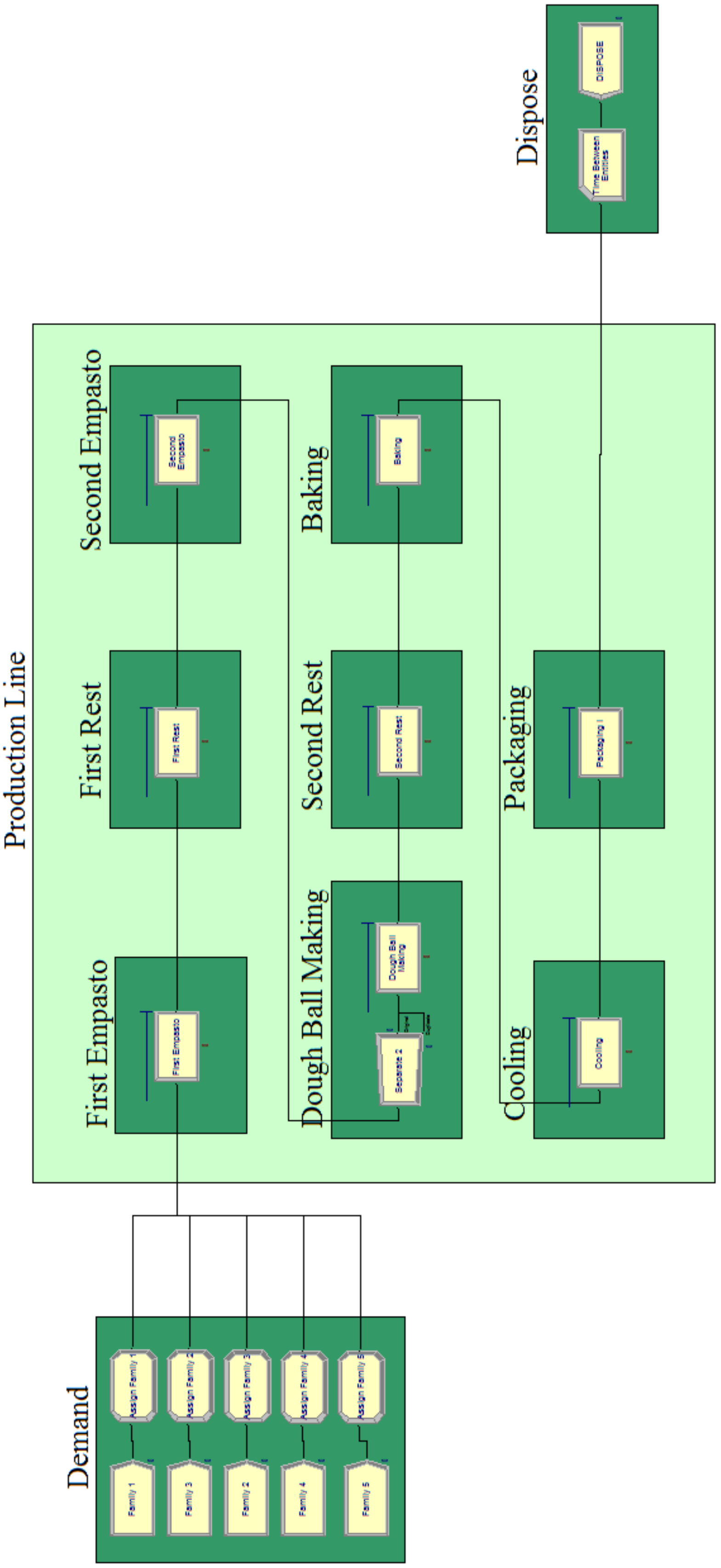
Consequently, the workstations of the phases First "*Empasto*", Second "*Empasto*", Dough Ball Making, Baking, and Packaging are represented respectively by mixers (for both, the first and second "*empastos*"), dough-ball-making machines, belt ovens, and packaging machines.

The before-mentioned approach of expressing the number of resources (machines) in the block *PROCESS* as $1/N_{jk}$, where the **variable** N_{jk} represents the number of resources k at workstation j, was also adopted in the case of *panettones* in order to consider the parallel effect of resources of the same type in a workstation.

It is worth mentioning that the number of belt ovens is represented with an additional **variable**, CAP_{jk} – just like the belt cooler for Easter eggs – to represent the maximum capacity of products that the belt oven can hold/ work concomitantly. Therefore, the number of belt ovens is represented as $1/(N_{jk} * CAP_{jk})$.

The use of the **variable** CAP_{jk} is also adopted for the phases First Rest, Second Rest and Cooling, whose resources are respectively rest areas (for both, the first and second rests) and coolers.

Figure 21 - Line-Balancing Model for Panettones

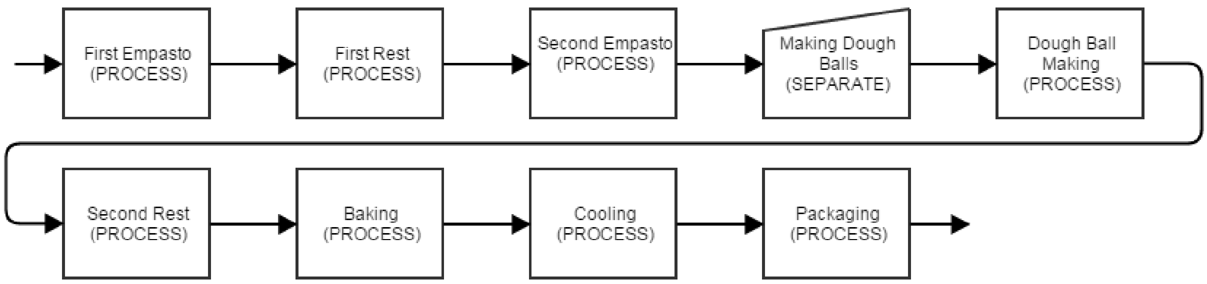


Production flow

As described earlier, after the preparation of the "*massa madre*", the manufacturing of *panettones* entails the following phases: (1) First "*Empasto*", (2) First Rest, (3) Second "*Empasto*", (4) Dough Ball Making, (5) Second Rest, (6) Baking, (7) Cooling, and (8) Packaging.

In order to reproduce the manufacturing process, each one of the phases' workstations was represented by the block *PROCESS*. In addition, a block *SEPARATE* was included in the production flow to address the split of the dough into smaller quantities by the dough-ball-making machine. This block retrieves the **attribute** AB, and generates $B_i - 1$ duplicated entities, where B_i is the amount of dough balls that can be made from the initial dough batch (which the company sizes according to the mixers' capacity). Figure 22 represents such rationale.

Figure 22 - Conceptual Model: Panettones Production Flow



It is worth observing that the block *SEPARATE* is placed before the block *PROCESS* related to the Dough Ball Making. That is, in such rationale, the split of the dough into smaller quantities takes place before the process responsible for it. The reason for this is that, according to Arena's functioning, the split/ separation does not consume time in the simulation. Thus, after the split, the original and the duplicated entities, each one representing a dough ball, are delayed by block *PROCESS* according to the required production time to make one dough ball.

Disposal of simulation entities

The disposal of the simulation entities is the same as in the case of Easter eggs: prior to the block *DISPOSE*, the project uses the block *RECORD* to compute the production line's cycle time (an indicative of its production capacity), which the company needs to run its financial model for capacity planning.

Furthermore, Arena's automatic report already indicates a possible service level by addressing the number of entities created and disposed during simulation. This report also specifies the resources' utilization rate, queue sizes and waiting times, which allows for the identification of the production line's bottleneck (the workstation with the longest waiting time and the highest resource utilization rate).

5.2.1 Verification of the Model

Similar to the case of Easter eggs, the Arena's student version does not allow the model to run with the company's data and reproduce the current manufacturing of *panettones*.

Furthermore, as the batches for *panettones* involves large amounts of product units, the project was not able to conduct a verification test with just one product family, like it was done for the Easter eggs.

Despite this issue, the project assessed the execution of the model with simple inputs, which were not related to the company's data. With such tests, the project observed if the model was replicating the manufacturing of *panettones* properly by analyzing the interactions between the flowchart blocks and entities, and their related attributes and variables.

5.2.2 Validation of the Model

The line-balancing model for *panettones* was presented jointly with the model for Easter eggs, and, just like the model of Easter eggs, the model received positive feedbacks, which showed the model's fit with the company's needs and expectations.

Still, the project was not able to perform a full simulation of the manufacturing of *panettones* in order to emphasize the model's support in identifying production bottlenecks and assessing the production line' operational performance.

The company's president and the operations director expressed that they will discuss the implementation of the line-balancing models for both, Easter eggs and *panettones*, for the next year (2016).

6 PRODUCTION-PLANNING MODEL

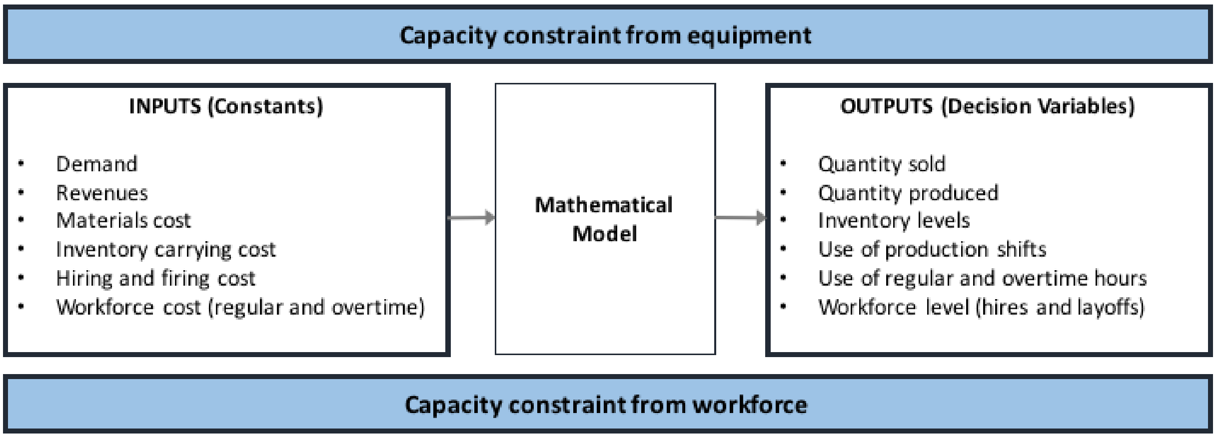
This chapter is dedicated to the explanation of the production-planning model. As the model rely on mathematical formulas, whose core rationale applies for both product categories – Easter eggs and *panettones* – in terms of inputs and outputs, objective function, and constraints, the model is explained in general terms.

The developed production-planning model takes into account the demand, the revenue (price), the materials cost and the inventory carrying cost for each product family. Moreover, it considers the related labor costs – hiring costs, salaries, wages and overtime payments – in addition to the capacity constraints derived from equipment and workforce. These are the model's **inputs** (**constants**, as the model can not change their value).

Concerning the model's **outputs**, it embraces the **decision variables** that are relevant to Company A's planning, providing insights about (1) when to begin the production of the holiday products; (2) the quantities to be produced, stored and sold of each product family; and (3) the allocation of workload among production lines. Moreover, the model supports the definition of (4) the staffing plan by indicating the number of workers necessary for each time period, the corresponding hires/ layoffs, the usage of shifts, and the use of regular and overtime hours.

Figure 23 summarizes the main parameters of the model.

Figure 23 - Diagram of the Production-Planning Model



It is important to highlight that model was developed in accordance to the Brazilian labor legislation in order to provide solutions adherent to reality. Consequently, the model adopts a plethora of inputs and outputs related to labor allocation and corresponding costs. Table 6 summarizes the legislation restrictions that concern workload.

Table 6 - Labor Time Restrictions

Period	Available Time per Day	Available Time per Week
Regular Time	8 Hours per Day	44 Hours per Week
Overtime	2 Hours per Day	12 Hours per Week

Table 7 outlines the restrictions regarding the workers payment.

Table 7 - Labor Payment Restrictions

Period	Payment Increment
Night Time	20%
Overtime	50%

As perceived in Table 6 and Table 7, an employee can work 8 hours from Monday to Friday and 4 hours on Saturday as part of its regular time. If such an employee works in the 3rd shift (night shift), it receives an increment of 20% over his salary. Furthermore, an employee can work two extra hours from Monday to Saturday, receiving an increment of 50% over his salary. If this employee performs his/ her extra hours during night time, the increment over his/ her baseline salary is 70% (20% from night plus 50% from overtime).

Table 8 shows the shifts and related payments that the model assumed in relation to the temporary workforce it addresses.

Table 8 - Shifts and Corresponding Payments assumed by the Model

Period	Shifts	Available Time	Payment
Regular Time	1st and 2nd Shifts (Daytime from Monday to Friday)	8 Hours per Day 5 Days per Week	Baseline salary
	3rd Shift (Night time from Monday to Friday)	8 Hours per Day 5 Days per Week	Salary incremented by 20%
	1st, 2nd and 3rd Shifts (On Saturday)	4 Hours per Day 1 Day per Week	Baseline wage
Overtime	1st Shift (Daytime from Monday to Friday, if available)	2 Hours per Day 5 Days per Week	Wage incremented by 50%
	1st and 2nd Shifts (Night Time from Monday to Friday, if available)	2 Hours per Day 5 Days per Week	Wage incremented by 70%
	1st, 2nd and 3rd Shifts (On Saturday)	2 Hours per Day 1 Days per Week	Wage incremented by 50%

The project also considered the following assumptions when developing the model:

- Variations in unitary revenues (price) and unitary costs (materials costs and inventory carrying costs) for each product family are assumed to be the constant throughout the planning horizon;
- Inventory carrying costs are applied to the inventory levels at the end of each time period. Thus, the goods produced and sold in the same period have inventory carrying cost equal to zero;
- Each time period is related to one month and the planning time horizon encompasses the entire time horizon available to produce the holiday products – seven months for Easter eggs, and four months for *panettones*;
- No outsourcing option is considered, as the company adopts this strategy for competitive reasons;
- The model embraces firing costs, even though the company is likely not to incur them by using the production-planning model. (According to the Brazilian labor legislation, the company does not incur any firing cost if it respects the deadlines of the pre-determined contracts with the temporary workers). Firing costs were included in the model, so they can be used by the decision-makers as penalties for having an oscillating workforce level throughout the production period, which may have a negative impact on the pool of workers;
- Hiring and firing costs, salaries and wages remain constant throughout the planning horizon;
- The model concerns just the hiring and firing of temporary workers used in the manufacturing of Easter eggs and *panettones*;
- Each production line requires a team with a fixed number of employees. The line can only be active if it presents the complete team required.

The production-planning model is presented below:

Indexes

i = Product family $(i = 1, \ldots, N)$

j = Production line $(j = 1, \ldots, J)$

s = Shift $(s = 1, 2, 3)$

t = Time period $(t = 1, \ldots, T)$

Inputs (Constants)

r_i = Average unitary revenue/ price for product family i [R$/ Unit]

g_i = Average unitary materials cost for product family i [R$/ Unit]

inv_i = Average unitary inventory carrying cost for product family i [R$/ Unit]

h = Cost of hiring one worker [R$/ Worker]

f = Cost of laying off one worker [R$/ Worker]

w = Salary for working in the 1st and 2nd shifts from Monday to Friday [R$/ Worker/ Month]

w' = Salary for working in the 3rd shift from Monday to Friday [R$/ Worker/ Month]

vw = Wage for working regular hours on Saturday [R$/ Worker/ Hour]

o = Wage for working overtime hours in the daytime from Monday to Friday [R$/ Worker/ Hour]

o' = Wage for working overtime hours in the night time from Monday to Friday [R$/ Worker/ Hour]

o'' = Wage for working overtime hours on Saturday [R$/ Worker/ Hour]

c_{ij} = Cycle time for product family i in production line j [Hours/ Unit]

rw_j = Required workforce for production line j [Workers]

d_{it} = Demand for product family i in month t [Units]

$dinf_{it}$ = Limit inferior of the demand for product family i in month t [Units]

a_t = Regular available hours per shift in month t – From Monday to Friday [Hours]

a''_t = Regular available hours per shift in month t – on Saturday [Hours]

exa_t = Extra available hours per shift in month t – From Monday to Friday [Hours]

exa''_t = Extra available time per shift in month t – on Saturday [Hours]

Outputs (Decision Variables)

S_{it} = Quantity sold of product family i in month t [Units]

X_{ijt} = Quantity produced of family i by production line j in month t – From Monday to Friday concerning the 1st and 2nd shifts [Units]

X_{it} = Quantity produced of family i in month t – From Monday to Friday concerning the 1st and 2nd shifts [Units]

X'_{ijt} = Quantity produced of family i by production line j in month t – From Monday to Friday concerning the 3rd shift [Units]

X'_{it} = Quantity produced of family i in month t – From Monday to Friday concerning the 3rd shift [Units]

X''_{ijt} = Quantity produced of family i by production line j in month t – on Saturday concerning the 1st, 2nd and 3rd shifts [Units]

X''_{it} = Quantity produced of family i in month t – on Saturday concerning the 1st, 2nd and 3rd shifts [Units]

Y_{ijt} = Extra quantity produced of family i by production line j in month t – From Monday to Friday in the daytime [Units]

Y_{it} = Extra quantity produced of family i in month t – From Monday to Friday in the daytime [Units]

Y'_{ijt} = Extra quantity produced of family i by production line j in month t – From Monday to Friday in the night time [Units]

Y'_{it} = Extra quantity produced of family i in month t during the week in the night time [Units]

Y''_{ijt} = Extra quantity produced of family i by production line j in month t – on Saturday [Units]

Y''_{it} = Extra quantity produced of family i in month t – on Saturday [Units]

I_{it} = Inventory level of product family i in month t [Units]

W_{jt} = Workforce level of production line j in month t for the 1st and 2nd shifts [Workers]

W'_{jt} = Workforce level of production line j in month t for the 3rd shift [Workers]

H_{jt} = Number of workers hired for production line j in month t [Workers]

F_{jt} = Number of workers fired for production line j in month t [Workers]

A_{jst} = State (active or inactive) of production line j during shift s in month t [0 or 1]

Objective Function

$$MAX\ \left[\sum_{i=1}^{N}(r_i * \sum_{t=1}^{T}(S_{it}))\right] - \left[\sum_{i=1}^{N}(g_i * \sum_{t=1}^{T}(X_{it} + X'_{it} + X''_{it} + Y_{it} + Y'_{it} + Y''_{it}))\right]$$

$$-\left[\sum_{i=1}^{N}\left(inv_i * \sum_{t=1}^{T}(I_{it})\right)\right] - \left[w * \sum_{t=1}^{T}\sum_{j=1}^{J}(W_{jt})\right] - \left[w' * \sum_{t=1}^{T}\sum_{j=1}^{J}(W'_{jt})\right]$$

$$-\left[vw * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(X''_{ijt})\right)\right)\right] - \left[o * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y_{ijt})\right)\right)\right]$$

$$-\left[o' * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y'_{ijt})\right)\right)\right] - \left[o'' * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y''_{ijt})\right)\right)\right] \quad (1)$$

$$-\left[h * \sum_{t=1}^{T}\sum_{j=1}^{J}(H_{jt})\right] - \left[f * \sum_{t=1}^{T}\sum_{j=1}^{J}(F_{jt})\right]$$

Constraints

$S_{it} \leq d_{it}$ $(i = 1, \dots, N); (t = 1, \dots, T)$ (2)

$S_{it} \geq dinf_{it}$ $(i = 1, \dots, N); (t = 1, \dots, T)$ (3)

$I_{it} = I_{i(t-1)} + X_{it} + X'_{it} + X''_{it} + Y_{it} + Y'_{it} + Y''_{it} - S_{it}$ $(i = 1, \dots, N); (t = 1, \dots, T)$ (4)

$\sum_{i=1}^{N}(c_{ij} * X_{ijt}) \leq a_t * (A_{j1t} + A_{j2t})$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (5)

$\sum_{i=1}^{N}(c_{ij} * X'_{ijt}) \leq a_t * A_{j3t}$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (6)

$\sum_{i=1}^{N}(c_{ij} * X''_{ijt}) \leq a''_t * \sum_{s=1}^{3} A_{jst}$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (7)

$\sum_{i=1}^{N}(c_{ij} * Y_{ijt}) \leq exa_t * \left(1 - A_{j2t}\right) * \left(1 - A_{j3t}\right) * (A_{j1t})$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (8)

$\sum_{i=1}^{N}(c_{ij} * Y'_{ijt}) \leq exa_t * \left(A_{j1t}\right) * \left(A_{j2t}\right) * \left(1 - A_{j3t}\right) * (A_{j1t} + A_{j2t})$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (9)

$\sum_{i=1}^{N}(c_{ij} * Y''_{ijt}) \leq exa''_t * \sum_{s=1}^{3} A_{jst}$ $(j = 1, \dots, J); (t = 1, \dots, T)$ (10)

$X_{it} = \sum_{j=1}^{J} X_{ijt}$ $(i = 1, \dots, N); (t = 1, \dots, T)$ (11)

$$X'_{it} = \sum_{j=1}^{J} X'_{ijt} \qquad (i = 1, \dots, N); (t = 1, \dots, T) \qquad (12)$$

$$X''_{it} = \sum_{j=1}^{J} X''_{ijt} \qquad (i = 1, \dots, N); (t = 1, \dots, T) \qquad (13)$$

$$Y_{it} = \sum_{j=1}^{J} Y_{ijt} \qquad (i = 1, \dots, N); (t = 1, \dots, T) \qquad (14)$$

$$Y'_{it} = \sum_{j=1}^{J} Y'_{ijt} \qquad (i = 1, \dots, N); (t = 1, \dots, T) \qquad (15)$$

$$Y''_{it} = \sum_{j=1}^{J} Y''_{ijt} \qquad (i = 1, \dots, N); (t = 1, \dots, T) \qquad (16)$$

$$W_{jt} + W'_{jt} = W_{j(t-1)} + W'_{j(t-1)} + H_{jt} - F_{jt} \qquad (j = 1, \dots, J); (t = 1, \dots, T) \qquad (17)$$

$$W_{jt} = rw_j * (A_{j1t} + A_{j2t}) \qquad (j = 1, \dots, J); (t = 1, \dots, T) \qquad (18)$$

$$W'_{jt} = rw_j * A_{j3t} \qquad (j = 1, \dots, J); (t = 1, \dots, T) \qquad (19)$$

$$A_{jst} = 0 \; or \; 1 \qquad (j = 1, \dots, N); (s = 1, \dots, N); \; (t = 1, \dots, T) \qquad (20)$$

All variables must be ≥ 0 (21)

$$I_{i(t=0)} = 0 \qquad (i = 1, \dots, N) \qquad (22)$$

$$W_{j(t=0)} = 0 \qquad (j = 1, \dots, J) \qquad (23)$$

$$W'_{j(t=0)} = 0 \qquad (j = 1, \dots, J) \qquad (24)$$

H_{jt} and F_{jt} must be integers $(j = 1, \dots, J); (t = 1, \dots, T)$ (25)

The objective function (equation (1)) represents the total gross margin that the company obtains with the sale of the product families.

As illustrated in Figure 24, the computation of the total gross margin considers the revenues received with the sales of the product families throughout the planning time horizon subtracting the costs related to raw material, inventory and workforce.

Figure 24 - Components of the Objective Function

$$MAX\ \left[\sum_{i=1}^{N}\left(r_i * \sum_{t=1}^{T}(S_{it})\right)\right] - \left[\sum_{i=1}^{N}\left(g_i * \sum_{t=1}^{T}(X_{it} + X'_{it} + X''_{it} + Y_{it} + Y'_{it} + Y''_{it})\right)\right]$$

Revenues — Materials cost

$$-\left[\sum_{i=1}^{N}\left(inv_i * \sum_{t=1}^{T}(I_{it})\right)\right] - \left[w * \sum_{t=1}^{T}\sum_{j=1}^{J}(W_{jt})\right] - \left[w' * \sum_{t=1}^{T}\sum_{j=1}^{J}(W'_{jt})\right]$$

Inventory cost — Salary (Monday to Friday - 1st and 2nd shifts) — Salary (Monday to Friday - 3rd shift)

$$-\left[vw * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(X''_{ijt})\right)\right)\right] - \left[o * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y_{ijt})\right)\right)\right]$$

Wage (Regular hours on Saturday - 1st, 2nd and 3rd shifts) — Wage (Overtime hours from Monday to Friday in the daytime)

$$-\left[o' * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y'_{ijt})\right)\right)\right] - \left[o'' * \sum_{j=1}^{J}\left(rw_j * \sum_{i=1}^{N}\left(c_{ij} * \sum_{t=1}^{T}(Y''_{ijt})\right)\right)\right]$$

Wage (Overtime hours from Monday to Friday in the night time) — Wage (Overtime hours on Saturday)

$$-\left[h * \sum_{t=1}^{T}\sum_{j=1}^{J}(H_{jt})\right] - \left[f * \sum_{t=1}^{T}\sum_{j=1}^{J}(F_{jt})\right]$$

Hiring cost — Firing cost

Equation (2) certifies that sales are equal or lower than their respective demand.

Equation (3) enables the decision makers to compel the model to meet the demand of some product families. It is important to remember that Company A will have some previously established subcontracting agreements when using the production-planning model. Therefore, the decision maker might want to ensure that the model satisfies such agreements before satisfying the forecasted demand of more profitable product families.

Equation (4) is an inventory-balance constraint, which takes into account the continuity of inventory levels from one time period to another.

Equations (11) to (16) combine the production levels from the production lines to simplify Equation (4). (The analysis of production level broken down in the lines provides relevant insights and, thus, it is reasonable to keep the decision variables X_{ijt}, X'_{ijt}, X''_{ijt}, Y_{ijt}, Y'_{ijt}

and Y''_{ijt} in the model). Equation (22) provides the value of $I_{i(t=0)}$, which is necessary for Equation (4) when $t = 0$.

Equations (5) to (10) are capacity constraints that limit production levels in accordance to the available regular and overtime hours. These equations uses the binary variable A_{jst} (equation (20) ensures that the variable is binary) to monitor the status of the shifts in the production lines, which can be inactive (0) or active (1).

Equation (5) addresses the use of regular hours in the 1st and 2nd shifts during the week (from Monday to Friday), while equation (6) is related to the use of regular hours in the 3rd shift. The use of one equation for the 1st and 2nd shifts and another for the 3rd shift is due to reporting reasons. This way, the decision maker can observe how much of the production is allocated to the daytime shifts (1st and 2nd shifts) and to the night shift (3rd shift), which is more costly in terms of labor cost. Equation (7) addresses the use of regular hour in these three shifts (1st, 2nd and 3rd shifts) on Saturday.

Equation (8) assesses if it is possible to use the 1st shift's available overtime hours during daytime. If the 2nd and 3rd shifts are both inactive, then it is possible to use these available overtime hours. Equation (9) follows the same rationale and analyzes if it is possible to use the 1st and 2nd shifts' available overtime hours. In this case, the 1st and 2nd shifts must be active while the 3rd one is inactive, so it is possible to use their available overtime hours during night time. It worth mentioning that the usage of the 2nd shift blocks the usage of the available overtime hours in equation (8) while it allows their usage in equation (9) – the other way round is also true – hence, it is not possible to use the 1st shift's available overtime hours twice.

Equation (10) addresses the use of overtime hours on Saturday.

Equation (17) considers the continuity of the workforce levels, subject to hires and layoffs, from one time period to another. In addition, equations (18) and (19) adjusts the workforce level according to the needs of each production line. At this point, it is important to observe that workforce level is broken down into W_{jt} (related to the 1st and 2nd shifts) and W'_{jt} (related to the 3rd shift) due to differences in their salaries (w and w' respectively).

Equations (23) and (24) provides the values of $W_{j(t=0)}$ and $W'_{j(t=0)}$, which are necessary for Equation (17) when $t = 0$. In addition, equation (25) ensures that H_{jt} and F_{jt} are integers (equations (18) and (19) already guarantee that W_{jt} and W'_{jt} are integers).

Equation (21) is a non-negativity constraint that ensures the model is not attributing negative values to the variables in order to maximize gross margin. For instance, in the lack of such constraint, the model could attribute negative values to inventory levels (solution not in line with reality) in order to make inventory costs positive and maximize gross margin.

A final remark worth highlighting is that the model does not adopt any continuity constraints in relation to the following months after the planning horizon (seven months for Easter eggs, and four for *panettones*). Consumption of holiday products just takes places during a specific time period, and their production uses temporary workers. Consequently, the continuity of inventory levels and workforce levels is not needed.

6.1.1 Chosen Tool for Running the Production-Planning Model

The project initially used Excel Solver to run the production-planning model, because the company is already familiar with the software Microsoft Excel, which is used in several planning activities such as demand forecasting and MPS. Therefore, the use of the software's own add-in would provide a familiar interface to the future users of the model, contributing to its implementation and long-lasting adoption.

However, the Excel Solver presented some instability issues when running the verification tests. Moreover, its limited capacity (in terms of number of constraints and binary variables) restrained the level of detail that the company needed for defining its staffing plan.

For these reasons, the project later adopted a third-party add-in, What'sBEST! by LINDO. As it is an add-in to Microsoft Excel, its interface is also familiar and friendly to the future users of the model. Furthermore, its stability proved to be far superior to Excel Solver's. It is worth highlighting that the company validated the use of What'sBEST!.

6.1.2 Verification of the Model: Easter Eggs

The project conducted several verification tests in order to eliminate errors and inconsistencies in the model. The remaining of this subsection contains the main charts and tables used in the assessment of the model's performance. APPENDIX E – VERIFICATION TESTS OF THE PRODUCTION-PLANNING MODEL contains the complete results from the verification scenarios. APPENDIX B – DATA FROM COMPANY A contains Company A's data, which were used in the verification tests.

In order to verify the production-planning model for Easter eggs, it was necessary to analyze whether its parameters were coherent with respect to (1) Workforce allocation, (2) Demand prioritization, (3) Inventory allocation, (4) Use of overtime, and (5) Production line prioritization.

Workforce allocation

One issue that is important to analyze is whether the model is prioritizing the allocation of workforce according to their related costs. To this end, the project ran the production-planning model with the company's current data, and assessed the use of workforce in relation to the use of shifts as well as regular and overtime hours.

Figure 25 - Use of Production Shifts during Regular Work Time

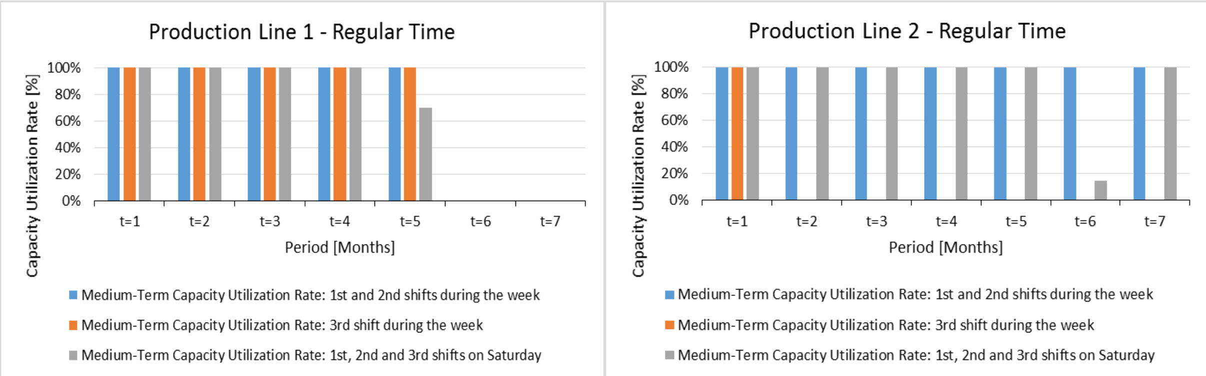
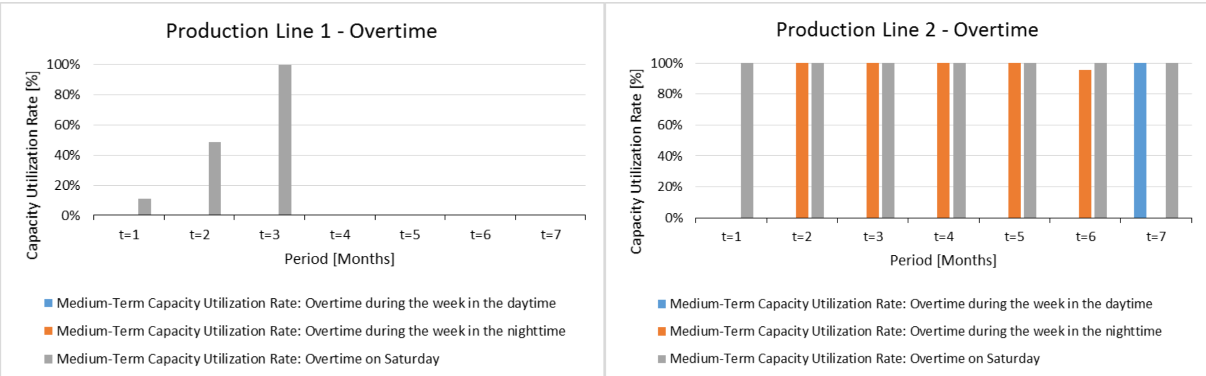


Figure 26 - Use of Production Shifts during Overtime



By analyzing results obtained, we can verify the model's adequacy in allocating the workforce.

The model prioritized the allocation of workers to the 1st and 2nd shifts during the week, rather than the 3rd shift, which is more costly. As observed in Figure 25 along with Figure 27, the prioritized shifts presented 100% utilization, while the unprioritized one was not even utilized in some instances. Figure 26 combined with Figure 27 show that the model prioritizes overtime during the week in the daytime, rather than in the night time (more costly), when possible (in the second production line during the seventh time period).

Figure 27 - Production Lines Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	Active	Active	Active
L1	t=2	Active	Active	Active
L1	t=3	Active	Active	Active
L1	t=4	Active	Active	Active
L1	t=5	Active	Active	Active
L1	t=6	Inactive	Inactive	Inactive
L1	t=7	Inactive	Inactive	Inactive
L2	t=1	Active	Active	Inactive
L2	t=2	Active	Active	Inactive
L2	t=3	Active	Active	Inactive
L2	t=4	Active	Active	Inactive
L2	t=5	Active	Active	Inactive
L2	t=6	Active	Active	Inactive
L2	t=7	Active	Inactive	Inactive

Demand prioritization

This analysis addresses how the model prioritizes demand fulfillment in face of capacity restrictions. Considering Company A's current production parameters, the model should follow the prioritization described in Table 9.

Table 9 - Product Families Prioritization

	F1	F2	F3	F4	F5	F6
Price [R$/ Unit]	4,64	13,34	14,14	3,49	8,48	10,82
Materials Cost [R$/ Unit]	1,20	4,62	8,48	0,80	1,69	2,49
Inventory Carrying Cost [R$/ Unit]	0,28	0,59	0,87	-	-	-
Margin [R$/ Unit]	3,16	8,12	9,54	2,69	6,79	8,33
Margin considering productivity [R$/ Second]	3,33	6,84	6,02	2,83	5,72	5,26
Prioritization Order	**5**	**1**	**2**	**6**	**3**	**4**

Figure 28 - Demand Fulfillment according to Capacity (I)

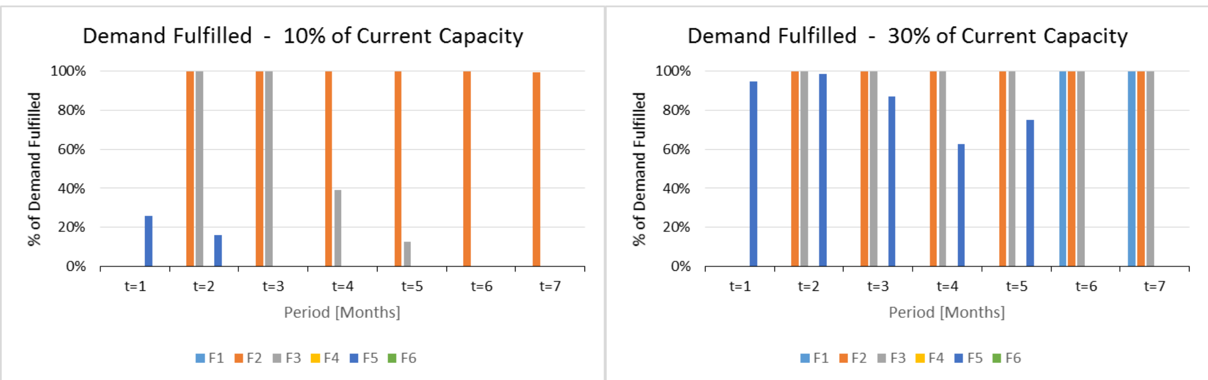
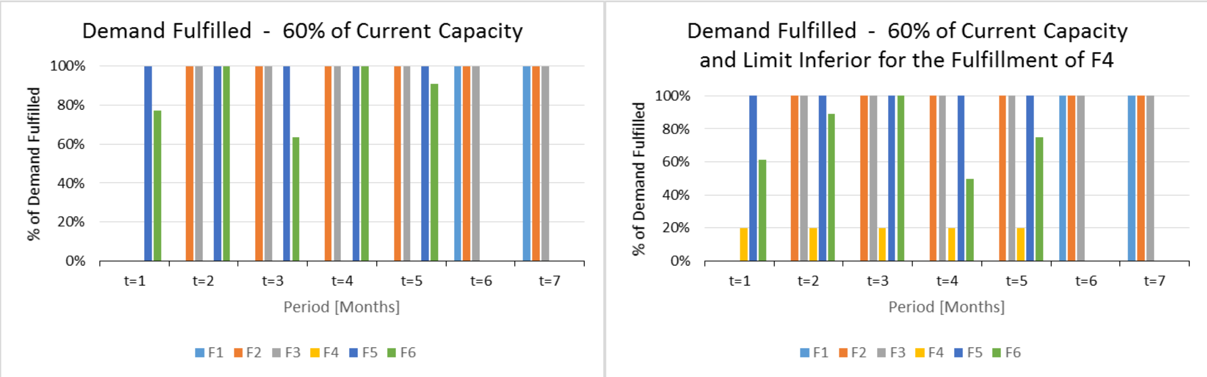


Figure 29 - Demand Fulfillment according to Capacity (II)



As Figure 28 and Figure 29 show, the model respect the ranking order described in Table 9, prioritizing the fulfillment of high-priority product families. For instance, with a 10%-capacity constraint, the model first fulfills the demand for product family F2, and then F3, and for last, F5. If capacity is increased to a 60% level, the next family to be fulfilled is F6. It is important to notice that F1 is fulfilled in the sixth and seventh time periods, because there is no demand for F4, F5 and F6 in these periods.

If the decision maker sets a minimum service level set for a low-priority product family, the model starts to prioritize its fulfillment. For instance, if the limit inferior for the fulfillment of the demand for F4 is 20%, the model starts to respect this condition – as Figure 29 illustrates.

Inventory allocation

Assuming that all the product families have the same price, production time and materials cost, the assessment of the model's inventory allocation is straightforward: the model should hold in inventory the families with the lowest inventory-carrying cost.

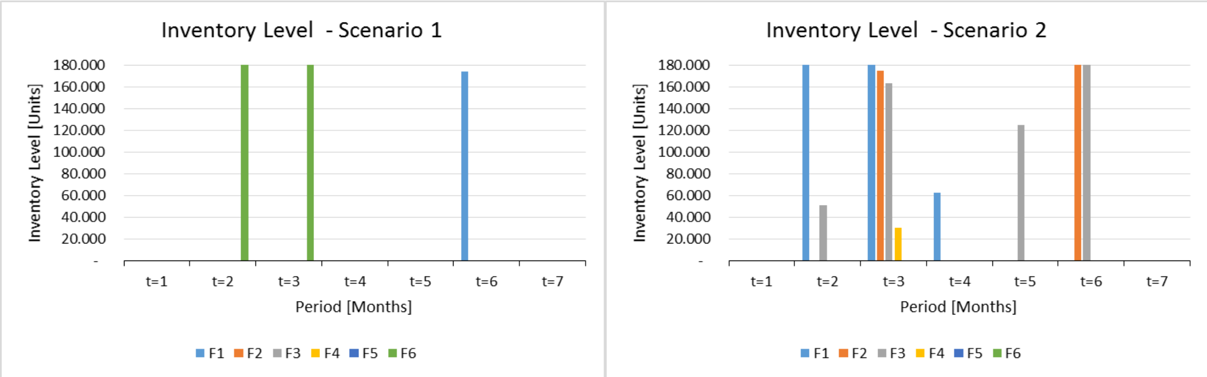
The project performed the verifications test attributing product family 2's price, production time and materials cost to the other existing families. Additionally, in order to ensure the model's consistency, the project ran two scenarios with the values of Table 10.

Table 10 - Inventory-Carrying Cost for Verification Scenarios

	F1	F2	F3	F4	F5	F6
Scenario 1 [R$/ Unit]	0,28	0,59	0,87	-	-	-
Scenario 2 [R$/ Unit]	-	-	-	0,28	0,59	0,87

As observed in Figure 30, the model proved to be consonant with such inventory allocation, holding product families with low or null inventory cost.

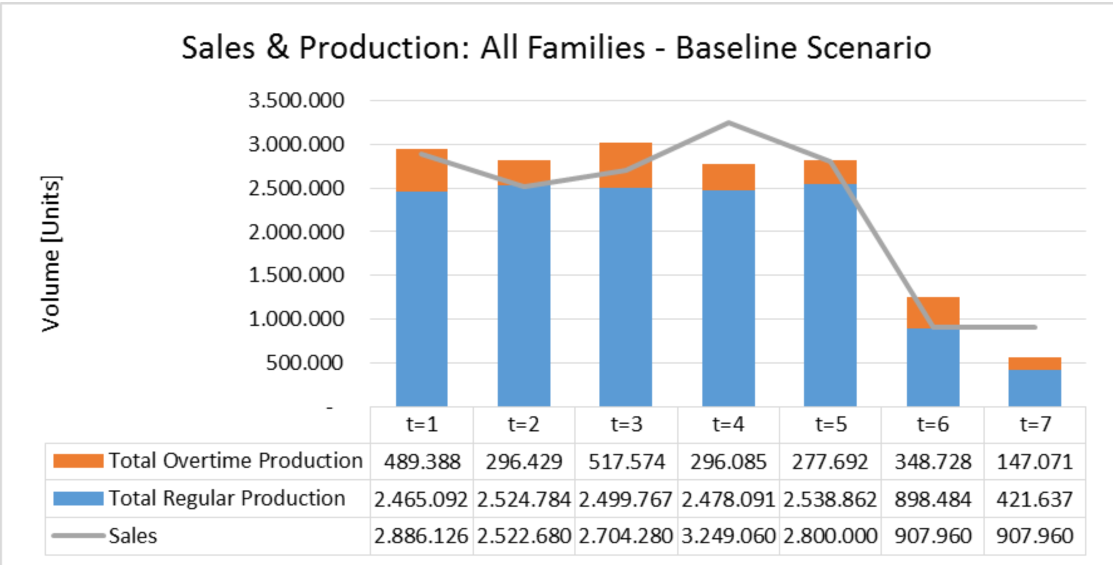
Figure 30 - Verification of the Monthly Allocation of Inventory Levels



Use of overtime

Considering the company's current data, total overtime production (2.372.966 units) is responsible for approximately 14.9% of total sales (15.978.066 units) – as Figure 31 shows.

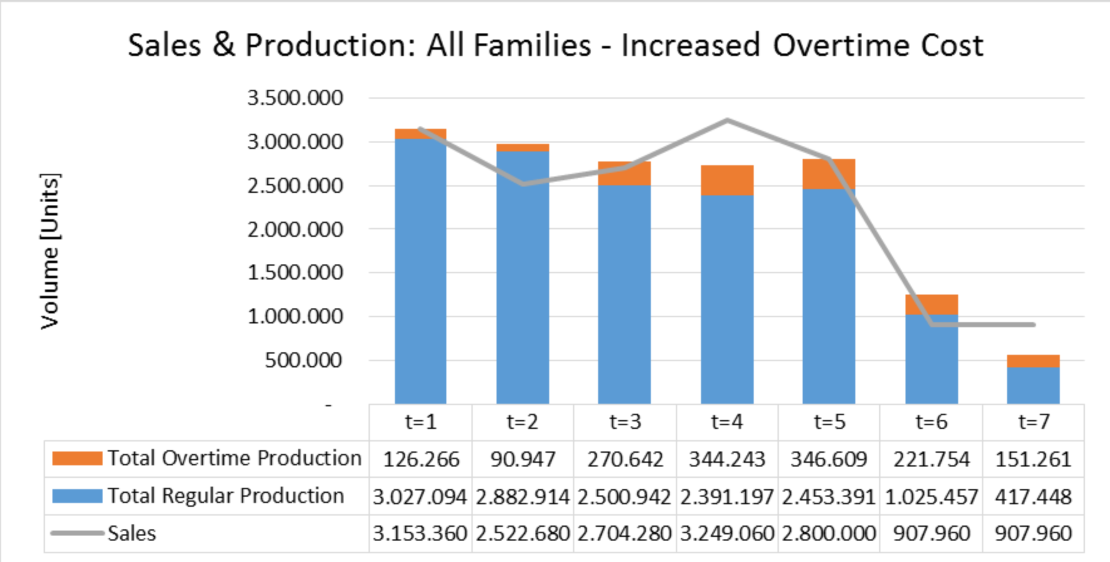
Figure 31 - Sales & Production for Easter Eggs: Baseline Scenario



	t=1	t=2	t=3	t=4	t=5	t=6	t=7
Total Overtime Production	489.388	296.429	517.574	296.085	277.692	348.728	147.071
Total Regular Production	2.465.092	2.524.784	2.499.767	2.478.091	2.538.862	898.484	421.637
Sales	2.886.126	2.522.680	2.704.280	3.249.060	2.800.000	907.960	907.960

If the overtime cost is increased (for instance, by five times), total overtime production (1.551.722 units) accounts for approximately 9.6% of total sales (16.245.300 units) – as Figure 32 shows. By analyzing the two scenarios, we can verify the model's adequacy in using overtime work. As overtime cost increases, the model tends not to chase the demand through overtime work.

Figure 32 - Sales & Production for Easter Eggs: Scenario with Increased Overtime Cost



	t=1	t=2	t=3	t=4	t=5	t=6	t=7
Total Overtime Production	126.266	90.947	270.642	344.243	346.609	221.754	151.261
Total Regular Production	3.027.094	2.882.914	2.500.942	2.391.197	2.453.391	1.025.457	417.448
Sales	3.153.360	2.522.680	2.704.280	3.249.060	2.800.000	907.960	907.960

Production line prioritization

This analysis addresses how the model allocates production between the two production lines of Easter eggs. According to the company's current parameters, both lines have the same cycle times for each of the product families.

By increasing the second line's cycle times by 5 times and the available production for both lines by 100% (in order to make the assessment in a straightforward way), the model must prioritize the first production line due to its higher production capacity.

Figure 33 - Production Line Prioritization: Regular Time

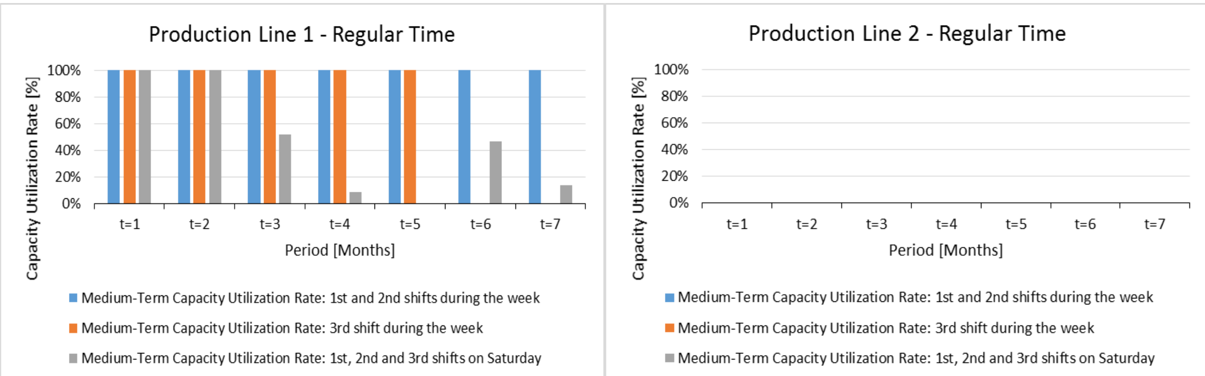
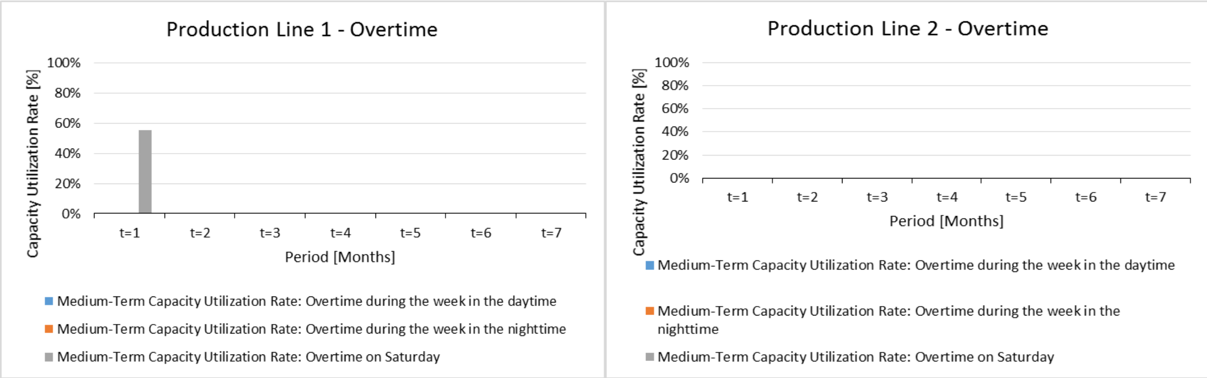


Figure 34 - Production Line Prioritization: Overtime



As observed in Figure 33 and Figure 34, the production allocation is properly done by the model, and the first production line is prioritized.

6.1.3 Verification of the Model: Panettones

The verification of the production-planning model for *panettones* involved the same tests conducted for Easter eggs: (1) Workforce allocation, (2) Demand prioritization, (3) Inventory allocation, and (4) Use of overtime. Production line prioritization was not conducted, because there is only one production line for *panettones*.

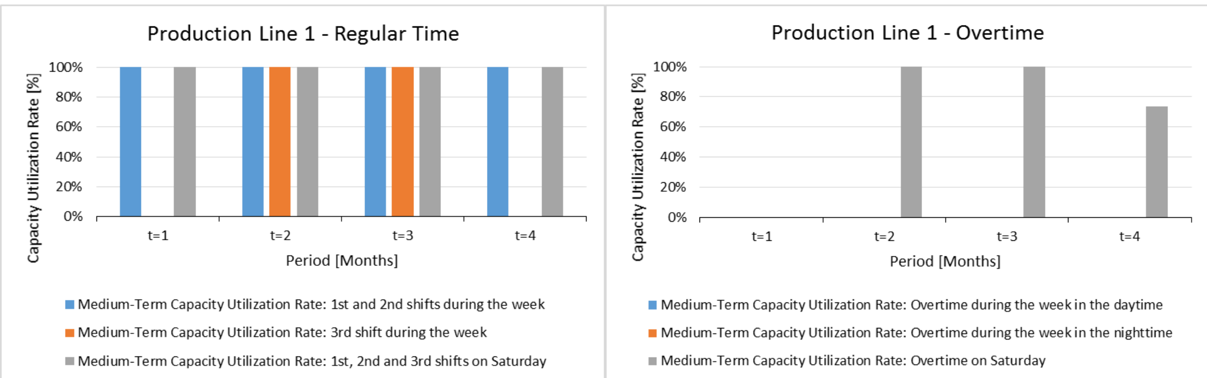
The remaining of this subsection discusses the verification tests briefly in order not to be redundant.

Workforce allocation

Similar to the verification test with Easter eggs, the model prioritized the allocation of workforce according to their related costs for the production of *panettones*.

The result from running the model with the company's current data is shown in Figure 35 and Figure 36.

Figure 35 - Workforce Allocation for the Panettones Production



During the week (regular time from Monday to Friday), the 1^{st} and 2^{nd} shifts were prioritized (indicated by their 100% utilization) as they have lower labor cost than the 3^{rd} shift.

The model also prioritized the overtime hours in the respective order, from the lowest to the highest labor costs: (1) overtime during the week in the daytime (when possible, that is, when just one shift is active during the month); (2) overtime on Saturday; (3) and overtime during the week in the night time.

Figure 36 - Use of Shifts for the Panettones Production

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	Active	Active	Inactive
L1	t=2	Active	Active	Active
L1	t=3	Active	Active	Active
L1	t=4	Active	Active	Inactive

Demand prioritization

The model also prioritized the fulfillment of *panettones* families that maximize the company's gross margin. Considering Company A's current production parameters, the model prioritized the families according to Table 11.

Table 11 - Product Families Prioritization for the Panettones Production

	F1	F2	F3	F4	F5
Price [R$/ Unit]	10,25	9,71	1,71	1,81	19,16
Materials Cost [R$/ Unit]	2,71	2,26	0,36	0,43	4,52
Inventory Carrying Cost [R$/ Unit]	0,71	0,71	0,11	0,11	1,43
Margin [R$/ Unit]	3,16	8,12	9,54	2,69	6,79
Margin considering productivity [R$/ Minute]	27.29	26.92	24.73	25.24	39.63
Prioritization Order	**2**	**3**	**5**	**4**	**1**

Figure 37 - Demand Prioritization for Panettones

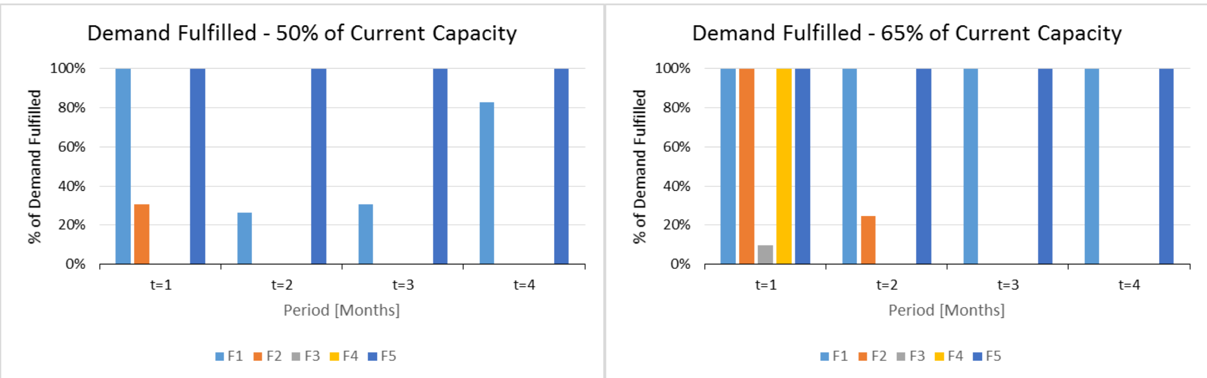
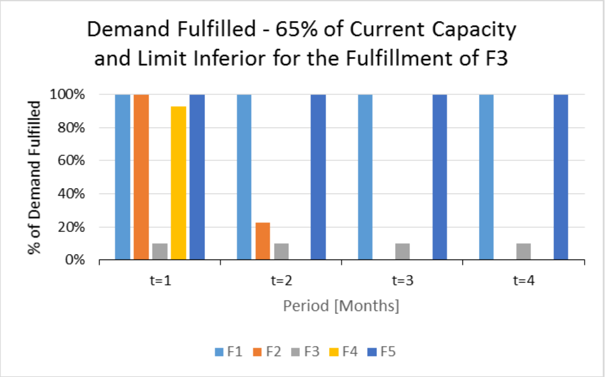


Figure 38 - Demand Prioritization for Panettones with Demand Fulfillment Constraint



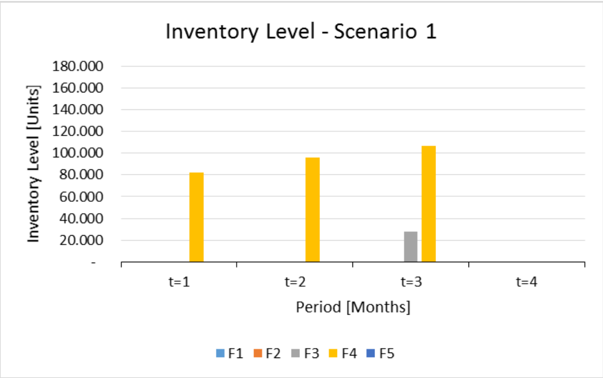
As Figure 37 and Figure 38 show, the model respected the prioritization order, and fulfilled the high-priority product families first. Except when a minimum service level was set for a low-priority product family (for instance, 10% for F3) – in this case, the model respected this constraint.

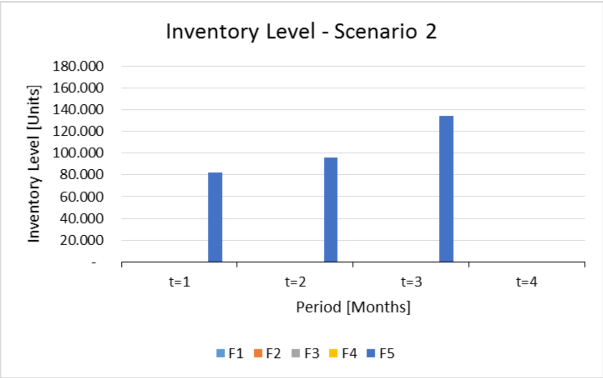
Inventory allocation

When all the product families have the same price, production time and materials cost (for instance, equal to product family 2), the model prioritized holding the families with the lowest inventory-carrying cost - as observed in Figure 39.

For a straightforward observation, the scenarios shown in Figure 39 also contain the following modifications in the company's current parameters. The demand for the months 1 to 3 was decreased by half, and increased by 400% for month 4. In scenario 1, all the product families have half of their respective inventory costs, and, in scenario 2, inventory cost of family F5 was decreased to zero.

Figure 39 - Monthly Allocation of Inventory Levels for Panettones



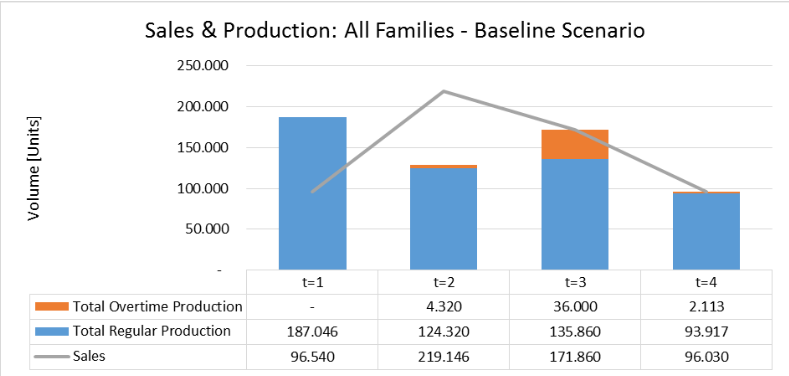


Use of overtime

In the case of *panettones*, the model also uses less overtime work as its cost increases. Considering the company's current data, as Figure 40 shows, total overtime production (42.433 units) accounts for approximately 7.3% of total sales (583.576 units).

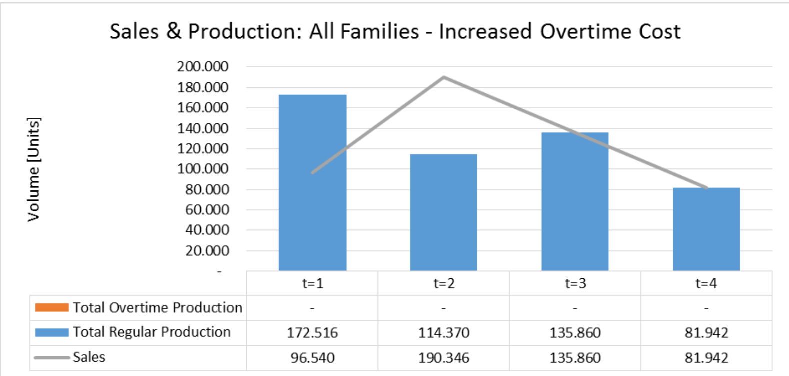
Conversely, if the overtime cost is increased (for instance, by five times), the model does not even use overtime work – as Figure 41 shows.

Figure 40 - Sales & Production for Panettones: Baseline Scenario



	t=1	t=2	t=3	t=4
Total Overtime Production	-	4.320	36.000	2.113
Total Regular Production	187.046	124.320	135.860	93.917
Sales	96.540	219.146	171.860	96.030

Figure 41 - Sales & Production for Panettones: Scenario with Increased Overtime Cost

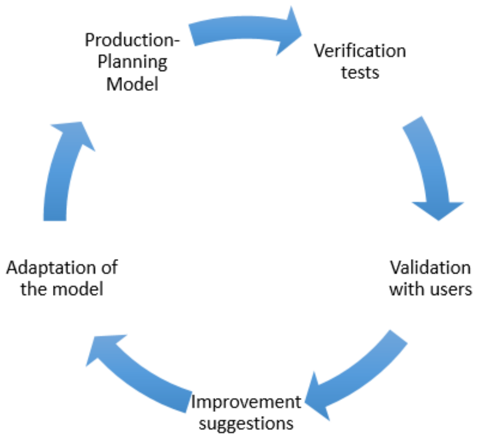


	t=1	t=2	t=3	t=4
Total Overtime Production	-	-	-	-
Total Regular Production	172.516	114.370	135.860	81.942
Sales	96.540	190.346	135.860	81.942

6.1.4 Validation of the Model: Easter Eggs and Panettones

The project adopted the iterative process illustrated in Figure 42 in the development and improvement of the production-planning model. Consequently, the project kept developing versions of model, performing verification tests on them, and validating them with the company.

Figure 42 - Iterative Process Used in the Development of the Production-Planning Model



The users' engagement in the validation sessions was critical to ensure that the model was in line with their needs, which increases the probability of its long-lasting adoption.

As the production-planning model deals with production-related and labor-related issues, the operations director, the PP&C manager and the HR manager participated in the model validation.

The PP&C manager will be the direct user of the model, and, consequently, contributed with inputs concerning his main decision points and the model's interface. On his turn, the operations director assessed the model in order to check if it was able to provide relevant insights to the planning process, and, ultimately, endorse its implementation.

Since the production-planning model supports the definition of a staffing plan, the HR manager participated in the model validation to check if it provided enough information for him to hire the temporary employees with the pre-determined contract, as the Brazilian labor legislation requires.

Their main contributions is summarized in Table 12.

Table 12 - Main Contributions from the Decision Makers in the Development of the Production-Planning Model

Comments	**Actions Taken**
Difficulty in understanding the model's mathematical programming	Friendly Interface
	Presentation to the operational director in order to emphasize the importance of the required training
Insufficient information to define the temporary workers' contracts	Usage of decision variables related to the detailed reporting of the usage of shifts and overtime hours

The first contribution that resulted in a meaningful adaption of the model was the PP&C manager's comment on his difficulty in understanding the mathematical programming of the model. Consequently, a friendly interface for the model was developed with the addition of two additional spreadsheets – one for entering the model's inputs, and another for presenting the simulation outputs. This way, the manager practically had no contact with the MILP formulas, contained in another spreadsheet (the "core" spreadsheet). The model interface is in the APPENDIX D – COMPLETE PRODUCTION-PLANNING MODEL. In addition, the model was presented to the operational director in order to obtain his endorsement for the training of the PP&C manager.

With respect to the HR manager's comments, most of them concerned the detailed reporting of labor-related information for him to be able to define the temporary worker's contracts. Consequently, the project added a plethora of variables to provide him insights not only about many workers to hire and fire in each month, but also the following matters:

- Allocation of temporary workers in the 1st, 2nd and 3rd shifts during the week (from Monday to Friday), as he basically sets a fixed salary for their monthly work in these shifts;
- Possible usage of regular hours on Saturdays, and overtime hours from Monday to Saturday. In this case, the workers already pronounce if they will be available to work on these hours during the settlement of the contract, and receive the wage according to the hours actually worked.

After the validation of the production-planning model with the PP&C manager, the HR manager and the operations director, the resulting model was presented to the president and the operations director. After the presentation, they declared that they intend to use the one-month free trial of What'sBEST! in the production planning of 2016/ 2017, and, then, decide upon the continuous use of the model and the investment in What'sBEST!.

6.1.5 Analysis of the Model's Impact: Easter Eggs and Panettones

When applied to the company's context, the production-planning model defied the company's current adopted production and workforce plans, which are based on the empirical knowledge of the company's decision-makers.

For instance, in the case of Easter eggs, this year's production started running under '2 shifts per day, 5 days per week' with overtime on Saturday. However, the company has already modified the initial plan, and has started to run a production line with 3 shifts per day.

The production-planning model, considering the company's current production parameters and aiming at maximizing the company's gross margin, suggested the following assertive plan (its details are in the APPENDIX F – PRODUCTION-PLANNING MODELS APPLIED TO THE COMPANY):

- **Production line 1**: It should be active for 5 months, and running 3 shifts per day. Overtime on Saturday is necessary just in the three first months;
- **Production line 2**: It should be active for the entire 7 months. However, it must run 3 shifts in the first month, 2 shifts from the second to the sixth month, and 1 shift in the seventh month. In addition, overtime should take place during the week (night time) and on Saturdays for most of the months.

In the case of *panettones*, Company A started running this year's production under '3 shifts per day, 5 days per week'. However, the company has stated that the plan will be modified to '2 shifts per day' soon (without stating the exact moment). The production-planning model, suggested the following plan (its details are in the APPENDIX F – PRODUCTION-PLANNING MODELS APPLIED TO THE COMPANY):

- **Production line for *Panettones***: It should be active for the entire four-month production period, running 2 shifts per day in the first and fourth months, and 3 shifts per day during the second and third months. In addition, overtime should take place on Saturday during the three last months.

Since the production period is shorter for *panettones*, the model is not able to suggest a plan completely diverse from the company's current one (for instance, suggesting the company to shut down the production after three months, because the inventory level is enough for the fourth month). Yet, it recommends a much more robust plan, based on operational and financial parameters.

Through the cases presented above, it is observed that the production-planning model can provide to the company's decision makers a robust basis for setting production, inventory and workforce levels in a more assertive and diagnostic way, and contribute to maximizing the company's gross margin.

7 IMPLEMENTATION OF THE MODELS

This section addresses the implementation of the line-balancing and the production-planning models.

In order to guarantee a tight coordination throughout the company's planning process and the successful adoption of the models, a four-stage framework was adopted to structure their implementation, which is as follows.

1. **General outline of the planning modules**: Definition of the functions and the timing of the developed models, as well as their respective planning modules according to the company's current hierarchical production planning;
2. **Assignment of tasks to the company's departments**: Allocation of the new tasks resulting from the developed models through (1) the modification of the SIPOC diagrams concerning the company's current planning processes and (2) the creation of new diagrams;
3. **Blueprint of the implementation**: Employment of the BPMN diagram in accordance with the results of the former two stages;
4. **Assessment of the implementation**: Analysis concerning if the addition of the new models causes strong disturbances in the company's current planning process, in a way that such disturbances jeopardize the success of their implementation. Disturbances in this context embrace the new data that the company must control and analyze, and the new tasks allocated to departments. If there is a strong disturbance, the project must develop a specific plan to tackle that disturbance in order to ensure the success of the models' implementation.

7.1.1 General Outline of the Planning Modules

The implementation of the line-balancing model does not require any modification in terms of the capacity planning module's time horizon and revision frequency: the model is intended to cover a three-year period with an annual revision frequency (just like the company's current financial engineering model for capacity planning that assesses the trade-off between 'operational performance vs cost'). The aggregate planning module (and its related production-planning model) is delineated as shown in Table 13.

Table 13 - General Outline of the Proposed Aggregate Planning Module

Module	Function	Time Horizon	Revision Frequency
Aggregate Planning	• Indication of when to begin/ end the production of the holiday products (Easter eggs and *panettones*) • Support of the staffing decisions related to the timing of hires and layoffs, as well as the usage of shifts and overtime • Allocation of production and inventory levels throughout the production period	Production period (seven months for Easter eggs/ four for *panettones*)	Yearly

Without any hindrance to the developed production-planning model, the aggregate planning module respects the timing of its predecessors (Long-term Forecasting and Capacity Planning) – which cover three-year periods and are revised yearly – and of its successor (MPS) – which covers the entire production period and is revised every two weeks.

The production-planning model is intended to be used yearly, before the beginning of the production period, and provides information about the workforce, production and inventory levels in the production period that will take place over the following months.

7.1.2 Assignment of Tasks to the Company's Departments

This subsection specifies the changes in Company A's production planning, which derive from the implementation of the developed models. These changes concern new tasks to be allocated to the company's departments, besides the modification of some existing ones. APPENDIX G – DIAGRAMS FOR COMPANY A'S FUTURE INFORMATION FLOW contains the SIPOC diagrams used as a basis for the specification of these changes.

The line-balancing model needs data about the shop floor, as it needs the production time of each workstation to reproduce each production line accordingly. Therefore, the operations department is responsible for proving this input for the model. Despite its nascent state, the company's control system monitors, yet inconstantly, such data, and is already able to feed the model.

As for the new outputs generated by the model, besides supporting the assessment of the lines' operational performance for the company's yearly capacity planning, the model also provides reliable information about the production lines' cycle time when an equipment has just been added (which is different than the one obtained during the production control of the previous year). Thus, when this is the case, the operations department can work with unlagged inputs about the production lines in the aggregate and MPS/ RCCP modules.

With respect to the production-planning model, it allocates the additional the task of determining an average price for product families to the Sales & Marketing department.

On their turn, the Purchasing and the Finance departments provide, respectively, the materials cost and the inventory cost needed for running the model. Currently, before the implementation of the production-planning model, they keep control of these variables for reasons related to accounting and budget. Therefore, they just need to provide these pieces of information to the Operations department.

The production-planning model also incites the participation of the HR department, as it not only provides the labor-related costs, but also contributes to the definition of a proper staffing plan.

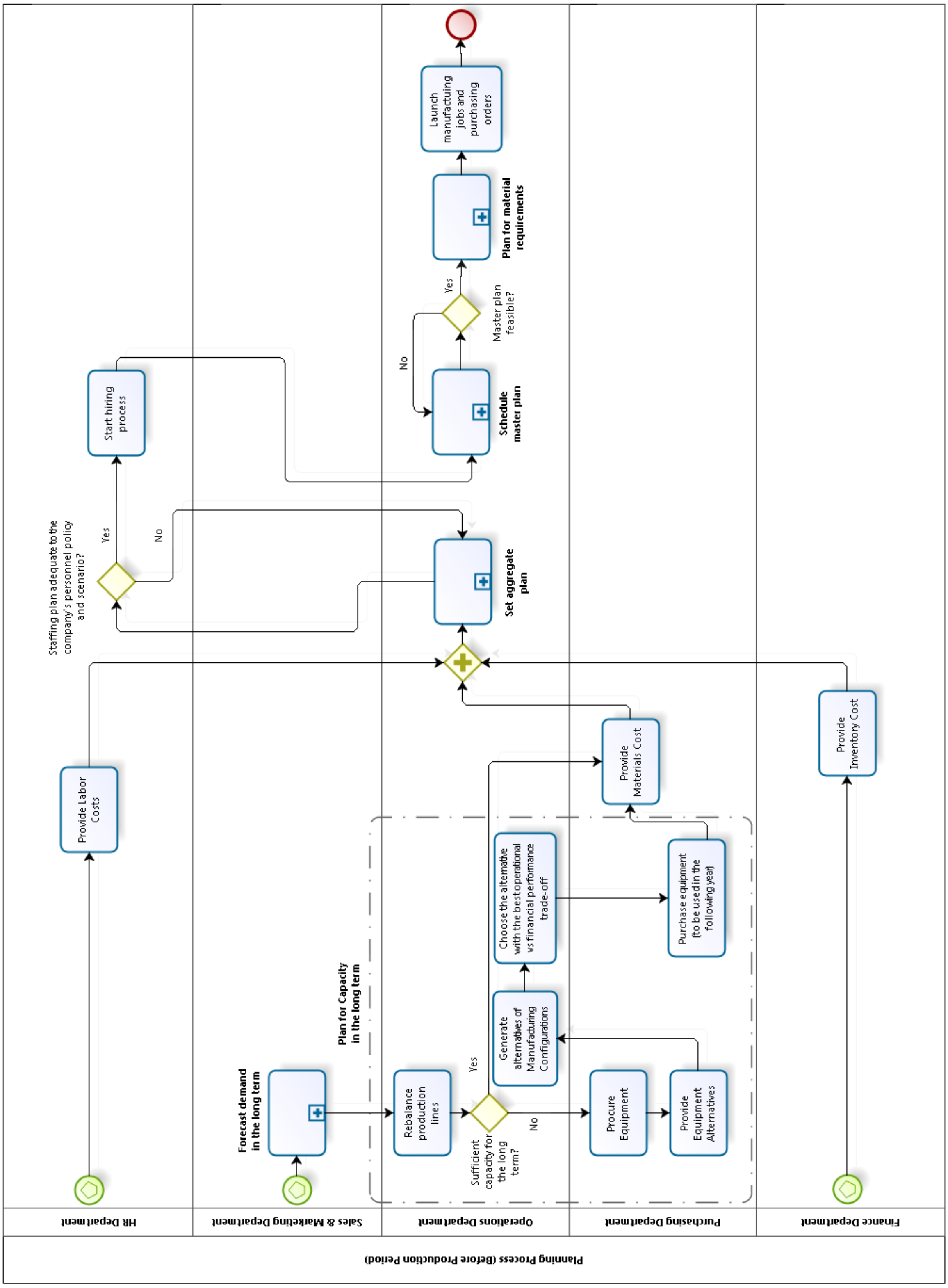
It is important to notice that the master production scheduling is intended to be done with the production goals (which are cost-aware and capacity-feasible) from the production-planning model, and not with the demand estimate from the long-term forecasting module.

Another remark is that the production-planning model provides the timing of hires and layoffs, as well as the usage of shifts and overtime, providing information about the short/ medium-term capacity for the RCCP module.

7.1.3 Blueprint of the Implementation

Figure 43 shows the BPMN diagram of Company A's production planning with the developed models implemented, which is in line with the general outline of the planning modules and the assignment of tasks to the company’s departments.

Figure 43 - BPMN Diagram of Company's Production Planning with Models Implemented



7.1.4 Assessment of the Implementation

This subsection evaluates the disturbances that the addition of the new models causes. It is important to notice that, in this context, disturbances refer to new data that the company must control and analyze, and new tasks allocated to departments.

The general outline of the company's planning process along with the use of the SIPOC and BPMN diagrams supported the project in identifying such disturbances, which are presented and analyzed in Table 14.

All aspects considered, as observed in Table 14, the new modules/ models do not impose any major disturbance that can jeopardize the success of their implementation.

With respect to the models, it is important to highlight that their use is quite simple (plug-and-play solutions). However, the learning of their modelling requires some time in order for the decision makers to start adapting them to the company's ever-evolving environment. The project considers this point as a subject that will follow after the models' initial years of use.

First, the company must recognize the relevance of models by using them. Later, with the recognition of their benefits, the company will tend to invest on the education/ training of the decision makers with regard to learning how to adapt the models to the future scenarios.

In order to guarantee the use of the models and the recognition of their importance, the project reinforced the models' impact on the company throughout the interactions with the top management. Furthermore, the project designated the PP&C manager as the project leader ("champion") for him to have responsibility over the implementation of the models. As he is their end user, and declared their great fit with his needs in the validation sessions, he is aligned with such responsibility.

Additionally, the project also stressed to the HR department the importance of studying the reform of the company's training and compensation policies after the initial use of the models, in order to incite the development of the employees.

Table 14 - Assessment of the Implementation

Department	**New Data/ New Tasks**	**Enablers**	**Assessment**
Sales & Marketing Department	•Computation of the product families' average price	The department has the inputs needed (price per item) to compute the product families' price	The computation does not require any mathematical model and, thus, the implementation is simple
Purchasing Department	•Providing the materials cost to the Operations department	The department already has control over the metric – it just needs to coordinate the information flow	Synchronization of information flow between departments – IT system can facilitate the process, but its absence does not impede the flow
Finance Department	•Providing the inventory cost to the Operations department		
HR Department	•Providing the labor costs to the Operations department		
	•Participating in the definition of the staffing plan	The department is responsible for the company's personnel policy	The department is aligned to participate in the production planning, as its participation later facilitates its work
Operations Department	•Running the line-balancing model •Running the production-planning model	The department itself does not need to generate more data to the models as inputs – the metrics it manages are sufficient for the models running	With the installation of the proper Excel Add-In (the project recommends What'sBEST!) and the simulation software Arena, the developed models are plug-and-play solutions

8 CONCLUSION

8.1 Project Synthesis

The present project aimed at improving the production planning of a food company with respect to its product categories that have seasonal demand.

To this end, the project began by assessing the company's production planning through the perspective of the hierarchical production planning framework along with the support of the process-mapping tools SIPOC and BPMN.

With the opportunities for improvement identified, the project dealt with two high-impact issues – capacity planning and aggregate planning –, developing decision-support models for both of them.

The first developed model, the line-balancing model, supports the yearly rebalance of the company's production lines. By supporting the identification of production bottlenecks, the rebalance of production lines, and the evaluation of their operational performance, the model allows the company's decision makers to determine the level of resources able to support the company's long-term competitive strategy in a more assertive way.

The second developed model, the production-planning model, provides the company a systematic way to work with aggregate data and production costs in its production planning, as it supports the definition of a capacity-feasible production plan that indicates the workforce, the production and the inventory levels in order to maximize the company's gross margin.

These models were developed with the participation of the company's decision makers in order to guarantee the fit with their needs. Furthermore, the project assessed how implementation of the developed models would affect the company in terms of the company's participating departments and data availability as well as the adopted software.

Coherent with the company's situation of yearly evaluating the purchase of new equipment to its production lines, the line-balancing model was developed using a simulation software for a neighborhood-search/ trial-and-error descriptive approach. Due to the limited capacity of free simulation software programs (the project tried to use Bizagi), the project adopted the well-recognized Arena by Rockwell Automation. The shortcoming of adopting it is that the project could not execute the developed model with the company's current data by using its student version, which jeopardized the presentation of the model to the company's president and operations director. Despite that, they expressed that they will consider its use in the production planning of 2016/2017.

The production-planning model was developed using What'sBEST!, which is a paid Excel Add-In. However, this add-in provides a six-month student license that provides full-functionality, and allowed the project to execute the developed model with the company's data. The results indicated that the model provides to the company's decision makers a robust basis for setting production, inventory and workforce levels in a more assertive and diagnostic way, and contribute to maximizing the company's gross margin. After the presentation of the model to the company's president and operations director, they stated that they intend to use the commercial version's one-month free trial in the production planning of 2016/ 2017. Then, they will decide upon the purchase of the Excel add-in.

Considering its development and outcomes, the project recognizes that it achieved its objectives.

8.2 Critical Analysis

Prior to the project, Company A already felt that it needed to improve and formalize its production planning processes. Yet, the discussions during the company's assessment reinforced this need, and made the company even more aware of it. The project already considers this as an important step towards the improvement of the production planning that the company seeks.

Besides that, the validation of the resulting models proves that the project was able to address the company's needs, and that it recognized the great benefits that the developed models bring to its production planning. The use of the line-balancing model is under consideration, while the production-planning model is intended to be adopted for the planning of 2016/2017.

Despite these positive results, the project acknowledges some limitations in its development and outcomes.

First, the use of the simulation software Arena and the restricted capacity of its student version did not allow the project to run the developed line-balancing model with the company's data, jeopardizing its presentation to the company's top management. The president and operations director showed less enthusiasm in adopting the model in comparison to the production-planning model, and the project mainly attributes this fact to the lack of simulation scenarios with the company's data.

Second, the project did not involve the reform of the company's compensation and training policies in face of the implementation of the developed models. This is an important issue, because it stimulates the development of the employees' competences to adapt the models throughout the company's ever-changing environment. Nevertheless, the project focused on the models and their fit with the decision makers' needs, because it regards the HR policy reform as a subject that will follow after the models' initial years of use. It is improbable that the company endorses a HR policy reform before using and recognizing the models' benefits during a few years. Still, the project acknowledges the importance of this reform, and highlighted it to the HR manager, the operations director and the company's president.

8.3 Further Developments

The developed models are intended to support the decision-making process in the company's production planning. Therefore, they do not provide undisputed/ single-pass solutions, and substitute Company A's existing decision makers.

As a matter of fact, the decision makers are key to evaluating the suggested solutions, revising their assumptions, and conducting a multi-pass decision-making process that leads to robust solutions (HOPP; SPEARMAN, 2008).

Therefore, in order to improve further its production planning, Company A must encourage its employees to have this iterative relationship with the models.

To this end, it can study the reform of its training and compensation plans in order to incite the development of the employees' competences along with the discerning posture needed from them.

The project already emphasized the importance of the production planning's human side to the HR manager. Moreover, such an importance was also emphasized to the company's president and operations director in order for them to support and endorse any future reform of the company's human resource policies.

In addition to enhancing the company's production planning through a reform in the its training and compensation policies, the project also identified some opportunities for improvement other than in the capacity planning and aggregate planning.

These opportunities – such as a causal model for long-term demand forecasting and an IT integration among participants of the production planning – were validated with the company's decision makers and recommended as a means for Company A to further improve its production planning.

8.4 Final Considerations

The project followed an interesting methodology for assessing and improving the Company A's existing production planning.

As observed in the literature review, there are few papers that focuses at the same time on both issues: assessing the whole production planning structure in a company and developing decision-support models accordingly. Usually, academic papers already begin focused on one issue of the production planning, such as production scheduling, inventory management, and the like. Therefore, the project may be useful to the community of practitioners that face the complexity of real-world manufacturing systems, and is uncertain about how to develop an action plan for improving their planning processes.

It is also worth mentioning that production-planning models often overlook the legal constraints involving labor. Consequently, such disregard can lead to solutions that are not adherent to reality. This is especially true in the Brazilian scenario, as the labor regulation is very strict. Thus, the theoretical discussion and the developed production-planning model may also be valuable in this aspect.

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10 APPENDIXES

APPENDIX A – DIAGRAMS FOR COMPANY A'S CURRENT INFORMATION FLOW

SIPOC Diagrams

These diagrams assessed how the company allocates the planning modules among its departments, and how the departments participate in them. Therefore, they focus on indicating the suppliers, the inputs, the outputs and the customers of each planning module.

SIPOC Diagram: Current Long-term Forecasting

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•Historical monthly sales of Easter eggs and *panettones* and from the past three years •Roadshow with contractors and retailers	Long-term Forecasting	•3-year monthly demand forecast •Preliminary sales mix	Operations Department

SIPOC Diagram: Current Demand Management

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•Real client orders	Demand Management	•Updated demand forecasting for the year in question •Updated sales mix	Operations Department

SIPOC Diagram: Current Capacity Planning

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•3-year demand forecast			
Operations Department	•Production lines' cycle time for each product family	Capacity Planning	•Re-balanced production configuration	Purchasing Department
Purchasing Department	•Possible equipment alternatives			

SIPOC Diagram: Current MPS

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•Demand forecast for the year in question •Sales mix	Master Production Scheduling	•Disaggregated demand in terms of product items	Operations Department

SIPOC Diagram: Current RCCP

Supplier	Input	Process	Output	Customer
Operations Department	•Disaggregated demand in terms of product items •Production lines' cycle times for each product item	Rough Cut Capacity Planning	•Feasible Master Schedule Plan	Operations Department
- (Assumed)	•Staffing Plan		•Adjusted staffing plan	HR Department

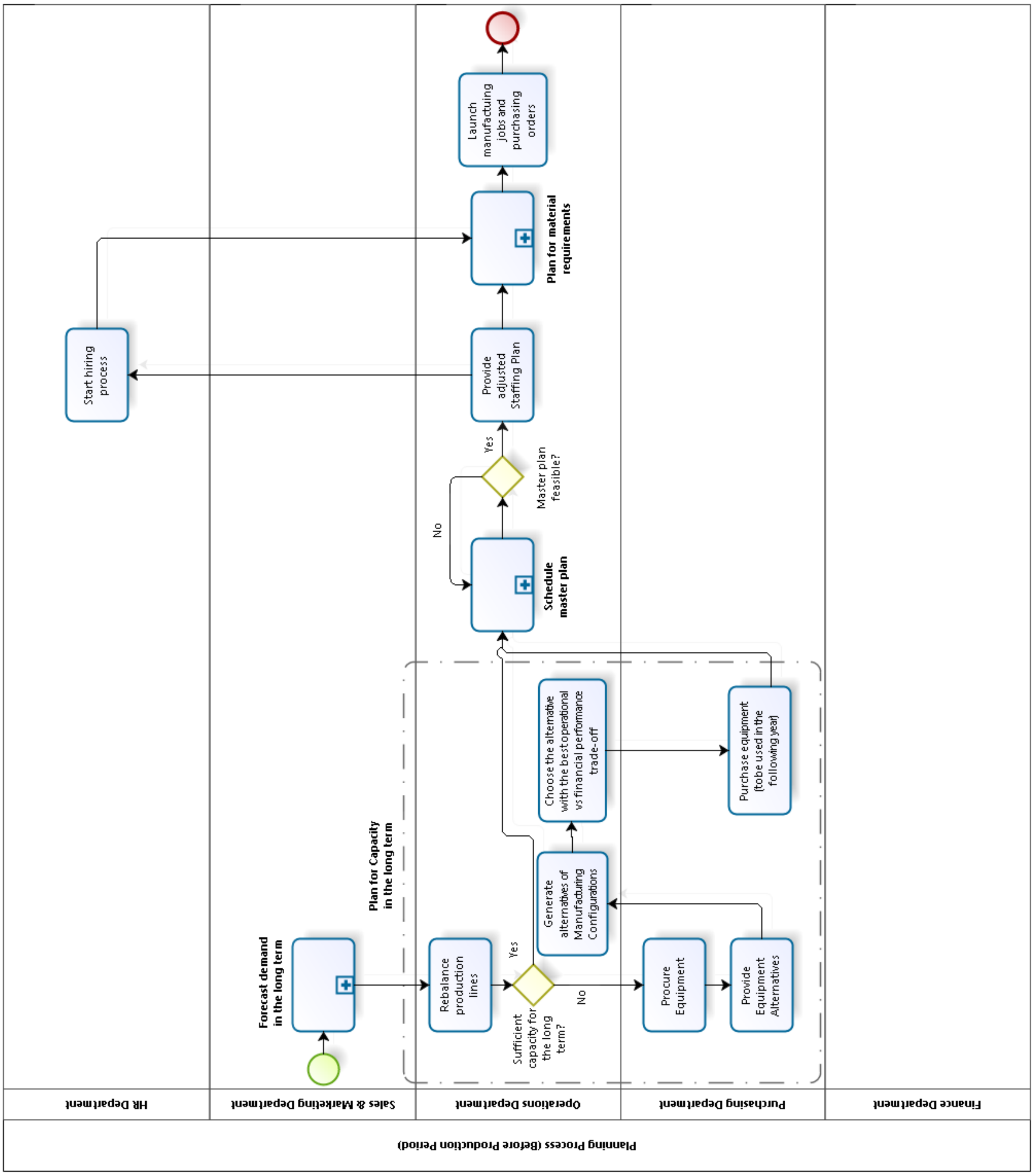
SIPOC Diagram: Current MRP

Supplier	Input	Process	Output	Customer
Operations Department	•Feasible Master Schedule Plan •Bill of materials •Inventory status •Production times	Materials Requirements Planning	•Manufacturing jobs	Operations Department
			•Purchasing orders	Purchasing Department

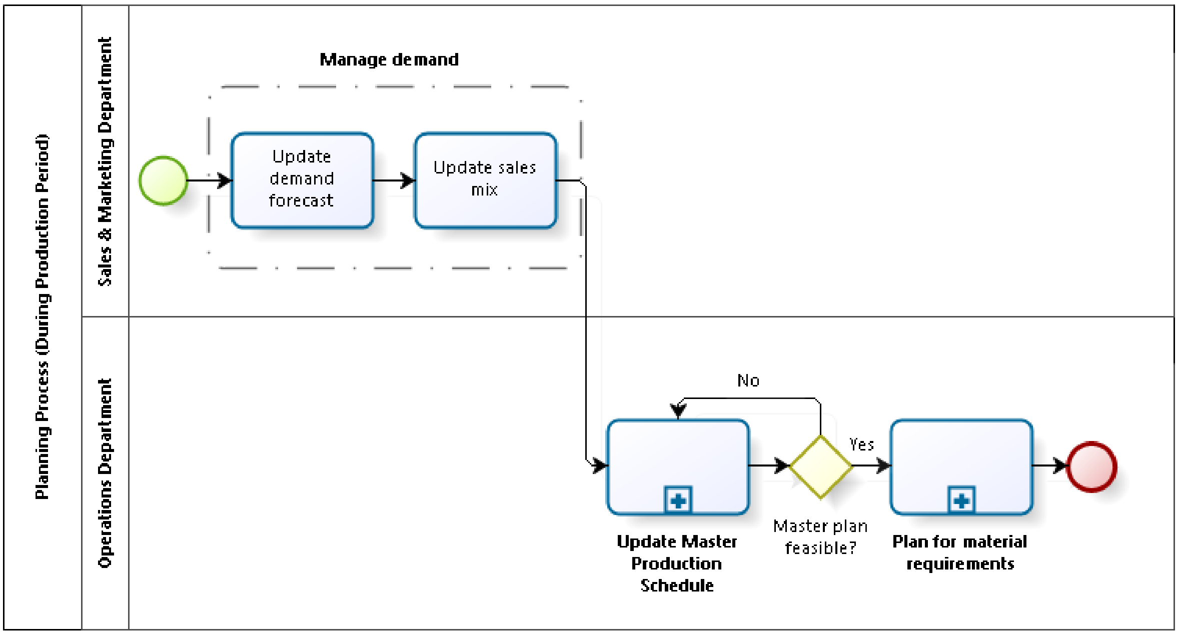
BPMN Diagrams

The BPMN diagrams focused on the planning-related information flows, and, therefore, the flows involving third parties, such as suppliers, were not considered (third parties do not participate in the company's production planning). Moreover, the project valued a simple representation to identify straightforwardly the synchronization among the company's departments. Hence, the diagrams (1) does not contain artifact elements to indicate data objects (these are already detailed in the SIPOC diagrams); and they (2) focused on representing the synchronization between the planning modules/ processes, representing the processes at a macro level (it does not go in-depth and represent them in terms of all of their tasks).

BPMN Diagram for the Current Production Planning (before production period)



BPMN Diagram for the Current Production Planning Revision (during production period)



APPENDIX B – DATA FROM COMPANY A

This appendix presents Company A's data used when running the developed models.

For the aggregation of the products in families, the project used the company's existing approach, which considers the similarities between the SKUs in terms of product features and financial structure.

The consideration of the products' financial structure is relevant, as the company has two different sorts of customers – retailers and contractors. Consequently, the contracts with each one of these customer types have clauses that make the product families have significant distinct financial characteristics.

It is important to mention that this report does not reveal in detail all the information provided by the company due to its request of confidentiality. To this end, the project clustered the company's product families in fewer families in order to prevent any inference on volumes from retailers and contractors.

Financials

The financial characteristics of each product family entail their price, material costs and inventory-carrying cost.

The company's materials cost contains the product families' necessary (1) raw material and (2) packaging material.

In relation to the inventory-carrying cost of Easter eggs, contractors take responsibility for the company's incurred inventory-carrying costs. This is why, families F4, F5 and F6 (concerning contractors' demand) have null inventory-carrying cost.

<u>Easter Eggs</u>

Financials [R$]			
Product Family	**Price**	**Materials Cost**	**Inventory-Carrying Cost**
F1	4,64	1,20	0,28
F2	13,34	4,62	0,59
F3	14,14	3,74	0,87
F4	3,49	0,80	-
F5	8,48	1,69	-
F6	10,82	2,49	-

Panettones

Financials [R$]			
Product Family	**Price**	**Materials Cost**	**Inventory-Carrying Cost**
F1	10,25	2,71	0,71
F2	9,71	2,26	0,71
F3	1,71	0,36	0,11
F4	1,81	0,43	0,11
F5	19,16	4,52	1,43

Demand

Company A provided the aggregate long-term (three-year) forecast for each of the clustered product families.

Easter Eggs

It is important to observe that the demand for families F4, F5 and F6 (concerning contractors' demand) is comprised in fewer months. Easter eggs contractors prefer to have their own products in advance to reduce the risk from unexpected events on the side of their subcontractors. In addition, they need time to distribute their products according to their logistic plan.

Demand (Year 1) [Units]							
	t=1	**t=2**	**t=3**	**t=4**	**t=5**	**t=6**	**t=7**
F1	-	68.746	137.493	206.240	274.988	343.728	343.728
F2	-	58.370	116.740	175.109	233.480	291.844	291.844
F3	-	54.478	108.957	163.435	217.915	272.388	272.388
F4	1.203.067	962.450	962.452	962.451	721.842	-	-
F5	1.042.318	833.852	833.854	833.853	625.393	-	-
F6	907.975	544.783	544.784	907.973	726.382	-	-

Demand (Year 2) [Units]	t=1	t=2	t=3	t=4	t=5	t=6	t=7
F1	-	72.184	144.368	216.551	288.737	360.914	360.914
F2	-	55.451	110.903	166.354	221.806	277.252	277.252
F3	-	43.583	87.166	130.748	174.332	217.910	217.910
F4	1.588.048	1.270.435	1.270.437	1.270.435	952.832	-	-
F5	1.125.704	900.560	900.562	900.561	675.424	-	-
F6	762.699	457.618	457.619	762.697	610.161	-	-

Demand (Year 3) [Units]	t=1	t=2	t=3	t=4	t=5	t=6	t=7
F1	-	72.184	144.368	216.551	288.737	360.914	360.914
F2	-	64.207	128.413	192.620	256.828	321.029	321.029
F3	-	57.202	114.405	171.607	228.810	286.007	286.007
F4	1.515.864	1.212.688	1.212.690	1.212.688	909.521	-	-
F5	1.438.399	1.150.716	1.150.718	1.150.716	863.042	-	-
F6	1.220.318	732.189	732.190	1.220.315	976.258	-	-

Panettones

Demand (Year 1) [Units]	t=1	t=2	t=3	t=4
F1	2.226	7.792	17.808	16.697
F2	40.956	92.170	51.198	20.482
F3	41.668	98.982	57.297	10.419
F4	2.671	8.015	21.370	21.372
F5	9.019	18.041	36.077	27.061
F6	2.226	7.792	17.808	16.697

Demand (Year 2) [Units]	t=1	t=2	t=3	t=4
F1	2.226	7.792	17.808	16.697
F2	40.956	92.170	51.198	20.482
F3	35.418	84.135	48.703	8.856
F4	2.270	6.813	18.164	18.166
F5	10.146	20.296	40.587	30.443
F6	2.226	7.792	17.808	16.697

Demand (Year 3) [Units]	t=1	t=2	t=3	t=4
F1	2.337	8.182	18.698	17.532
F2	43.004	96.778	53.758	21.506
F3	37.501	89.084	51.568	9.377
F4	2.404	7.213	19.233	19.235
F5	11.837	23.679	47.351	35.517
F6	2.337	8.182	18.698	17.532

Workforce Costs – Both Product Categories

Company A provided the current salaries and wages it pays to its workers.

With respect to the hiring and firing costs, the firm incurs relatively low hiring costs due to its relatively stable pool of candidates. In addition, if it respects the deadline of the contracts with the temporary workers, it incurs no firing costs. However, these costs were raised when running the production-planning model in order for the model to provide solutions with more stable workforce allocation, not jeopardizing the workers' morale.

Salaries [R$/ Employee]	
Regular Time during the week (1st and 2nd shifts)	**Regular Time during the week (3rd shift)**
1.350	1.620

Wages [R$/ Hour]			
Regular Time on Saturday (1st, 2nd and 3rd shifts)	**Overtime during the week (daytime)**	**Overtime during the week (nighttime)**	**Overtime on Saturday**
8,50	12,70	14,45	12,90

Other Workforce-related costs [R$/ Employee]	
Hiring Cost	**Firing Cost**
100	400

Theoretical Available Time – Both Product Categories

The computation of the available time for each time period considered the available working days in each month and the effective working time of each shift.

Available Time Per Shift Per Month [Hours]				
Period	**Regular Time during the week (1st, 2nd and 3rd shifts)**	**Regular Time on Saturday (1st, 2nd and 3rd shifts)**	**Overtime during the week (daytime or nighttime)**	**Overtime on Saturday**
t=1	151	20	42	10
t=2	151	16	42	8
t=3	151	20	42	10
t=4	144	16	40	8
t=5	158	16	44	8
t=6	144	20	40	10
t=7	151	16	42	8

Required Workforce

The required workforce for each production line entails the temporary workers that are hired to do the following tasks: (1) handling and supplying raw/ in-process material to the workstations, (2) putting in and taking out from the machines the necessary raw/ in-process material, and (3) monitoring the functioning of the equipment.

<u>Easter eggs</u>

The required workforce for the production line of Easter eggs also embraces the temporary workers responsible for (4) packaging the finished items.

Required Workforce [Employees]	
Production Line	**Required Workforce**
L1	150
L2	150

Panettones

Required Workforce [Employees]	
Production Line	**Required Workforce**
L1	125

Production Times by Production Line

The data concerning the production times of each product line with respect to the product families, results from the monitoring that company performed in the beginning of the current year (Year 1)'s production period. It is worth mentioning that the monitoring of the *panettone* production line has not been made so far in the current year, which points towards the inconsistency of the current monitoring system. Company A's current endeavor entails the improvement of this system.

Easter eggs

Production Times [Seconds/ Unit]		
	L1	L2
F1	0,95	0,95
F2	1,19	1,19
F3	1,58	1,58
F4	0,95	0,95
F5	1,19	1,19
F6	1,58	1,58

Panettones

Production Times [Minutes/ Unit]	
	L1
F1	0,25
F2	0,25
F3	0,05
F4	0,05
F5	0,33

Workstations Configuration

Easter Eggs

Production Lines 1 and 2: Families 3 and 5			
Workstation	**Resource**	**Production Time**	**Unit**
Chocolate Tempering	Tempering Machine	TRIA(76; 80; 83)	Seconds/ Batch
Chocolate Dripping	Chocolate Dripping Machine	TRIA(168; 170; 172)	Seconds/ Batch
Centrifugation	Centrifuge 1	TRIA(11,9; 12; 12,2)	Minutes/ Batch
	Centrifuge 2	TRIA(11,9; 12; 12,2)	Minutes/ Batch
	Centrifuge 3	TRIA(11,9; 12; 12,2)	Minutes/ Batch
	Centrifuge 4	TRIA(11,9; 12; 12,2)	Minutes/ Batch
	Centrifuge 5	TRIA(11,9; 12; 12,2)	Minutes/ Batch
	Centrifuge 6	TRIA(11,9;12; 12,2)	Minutes/ Batch
Chocolate Cooling	Belt Cooler	TRIA(9,8; 10; 10,2)	Minutes/ Book
Packaging I	Worker	TRIA(17;20;23)	Seconds/ Egg
Packaging II	Worker	TRIA(75;90;110)	Seconds/ Egg

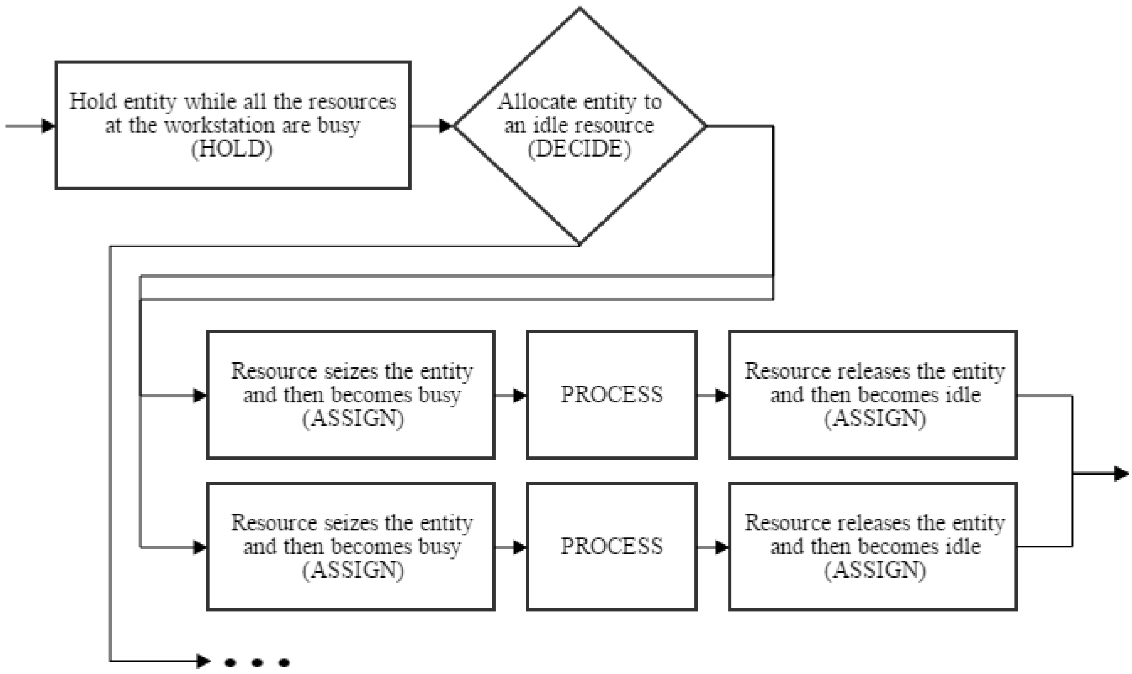
Technical Aspects	
Centrifuges’ Capacity	28 Books/ Centrifuge
Belt Cooler’s Capacity	50 Books/ Belt Cooler
Workers in Packaging I	24 Workers
Workers in Packaging II	50 Workers
“*Livro*” for Families 3 and 5	6 Eggs/ Book

APPENDIX C – LINE-BALANCING MODEL: RATIONALE FOR DIFFERENT RESOURCES AT THE SAME WORKSTATION

If a workstation holds more than one type of resource type, the block *HOLD* can be used to hold the entities (products) while no resource of the workstation is available for manufacturing them.

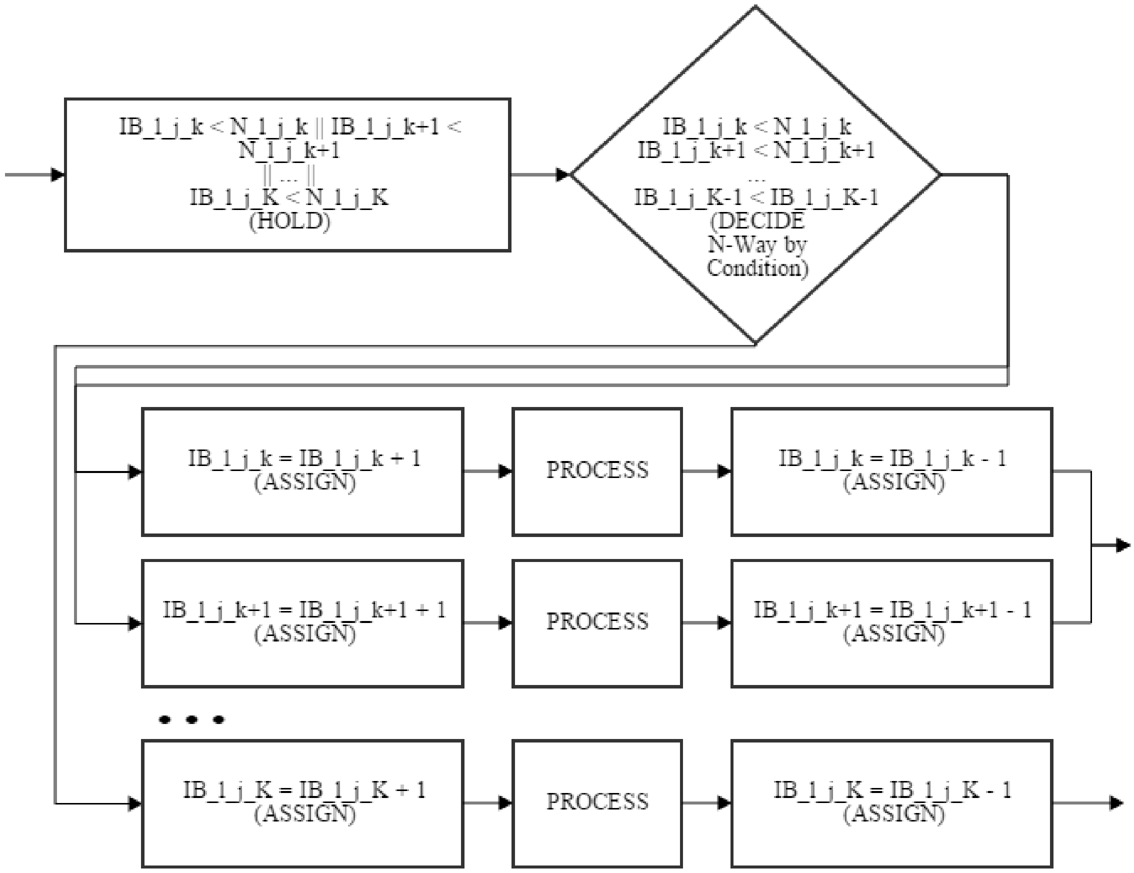
This approach allows the Arena to keep track of the block *HOLD's* queue waiting time, which indicates whether the workstation in question is a production bottleneck. If the block were not used, the entities would be allocated to each resource type (represented by the block *PROCESS*) and the Arena would keep track of the queue waiting time of each block *PROCESS*, hindering the straightforward indication of the combined queue for the workstation.

The rationale of the approach with the block *HOLD* is as follows.



The implementation of the rationale requires the use of the **variable** BI_{ljk} in order to variable indicates whether there is a product being manufactured by the resource k at the workstation j of production line l, that is, whether the resource in question is busy or idle.

It is worth mentioning that the use of the **variable** N_{ljk} to consider the parallel effect of resources of the same type is still adopted. The use of the variable combined with the rationale is the following.


IB_1_j_k < N_1_j_k || IB_1_j_k+1 < N_1_j_k+1
|| ... ||
IB_1_j_K < N_1_j_K
(HOLD)
IB_1_j_k < N_1_j_k
IB_1_j_k+1 < N_1_j_k+1
...
IB_1_j_K-1 < IB_1_j_K-1
(DECIDE
N-Way by
Condition)
IB_1_j_k = IB_1_j_k + 1
(ASSIGN)
PROCESS
IB_1_j_k = IB_1_j_k - 1
(ASSIGN)
IB_1_j_k+1 = IB_1_j_k+1 + 1
(ASSIGN)
PROCESS
IB_1_j_k+1 = IB_1_j_k+1 - 1
(ASSIGN)
IB_1_j_K = IB_1_j_K + 1
(ASSIGN)
PROCESS
IB_1_j_K = IB_1_j_K - 1
(ASSIGN)

APPENDIX D – COMPLETE PRODUCTION-PLANNING MODEL

In order not to be redundant, this appendix presents the screenshots of the production-planning model for Easter eggs. The model for *panettones* has the same interface; it just differs in the extent of model, as the manufacturing of *panettones* entails a lower number of production lines. product families, and production months.

Easter Eggs

Input Spreadsheet: Partial Screenshots

Name	Symbol	Unit	Unchanging -
Revenue per unit sold	r_i		
Product Family 1	r_1	Reais/ Unit	
Product Family 2	r_2	Reais/ Unit	
Product Family 3	r_3	Reais/ Unit	
Product Family 4	r_4	Reais/ Unit	
Product Family 5	r_5	Reais/ Unit	
Product Family 6	r_6	Reais/ Unit	
Materials cost	g_i		
Product Family 1	g_1	Reais/ Unit	
Product Family 2	g_2	Reais/ Unit	
Product Family 3	g_3	Reais/ Unit	
Product Family 4	g_4	Reais/ Unit	
Product Family 5	g_5	Reais/ Unit	
Product Family 6	g_6	Reais/ Unit	
Inventory Carrying Cost	inv_i		
Product Family 1	inv_1	Reais/ Unit	
Product Family 2	inv_2	Reais/ Unit	
Product Family 3	inv_3	Reais/ Unit	
Product Family 4	inv_4	Reais/ Unit	
Product Family 5	inv_5	Reais/ Unit	
Product Family 6	inv_6	Reais/ Unit	
Hiring cost	h	Reais/ Employee	
Firing cost	f	Reais/ Employee	
Workforce regular time cost - Regular Shift	w	Reais/ (Employee * Month)	
Workforce regular time cost - Night Shift	w'	Reais/ (Employee * Month)	
Workforce variable regular time cost - Saturday	vw	Reais/ (Employee * Hour)	
Workforce overtime cost - During the week (not during night time)	o	Reais/ (Employee * Hour)	
Workforce overtime cost - During the week (during night time)	o'	Reais/ (Employee * Hour)	
Workforce overtime cost - On Saturday	o''	Reais/ (Employee * Hour)	
Cycle Time	c_i_j		
Product Family 1 - Prodution Line 1	c_1_1	Hours/ Unit	
Product Family 1 - Prodution Line 2	c_1_2	Hours/ Unit	
Product Family 2 - Prodution Line 1	c_2_1	Hours/ Unit	
Product Family 2 - Prodution Line 2	c_2_2	Hours/ Unit	
Product Family 3 - Prodution Line 1	c_3_1	Hours/ Unit	
Product Family 3 - Prodution Line 2	c_3_2	Hours/ Unit	
Product Family 4 - Prodution Line 1	c_4_1	Hours/ Unit	
Product Family 4 - Prodution Line 2	c_4_2	Hours/ Unit	
Product Family 5 - Prodution Line 1	c_5_1	Hours/ Unit	
Product Family 5 - Prodution Line 2	c_5_2	Hours/ Unit	
Product Family 6 - Prodution Line 1	c_6_1	Hours/ Unit	
Product Family 6 - Prodution Line 2	c_6_2	Hours/ Unit	
Required workforce per Production Line	rw_j		
Prodution Line 1	rw_1	Employees	
Production Line 2	rw_2	Employees	

Name	Symbol	Unit	Unchanging	Time Line [Months]							
Name	Symbol	Unit	-	1	2	3	4	5	6	7	TOTAL
Demand	d_i_t										
Product 1	d_1_t	Units									-
Product 2	d_2_t	Units									-
Product 3	d_3_t	Units									-
Product 4	d_4_t	Units									-
Product 5	d_5_t	Units									-
Product 6	d_6_t	Units									-
Demand - Inferior Limit	dinf_i_t										
Product 1	dinf_1_t	Units									-
Product 2	dinf_2_t	Units									-
Product 3	dinf_3_t	Units									-
Product 4	dinf_4_t	Units									-
Product 5	dinf_5_t	Units									-
Product 6	dinf_6_t	Units									-
Regular Available Time - Per Shift (during the week)	a_t	Hours/ Month									-
Regular Available Time - Per Shift (on Saturday)	a''_t	Hours/ Month									-
Available Time for Overtime - Per Shift (during the week)	exa_t	Hours/ Month									-
Available Time for Overtime - Per Shift (on Saturday)	exa''_t	Hours/ Month									-

Input Spreadsheet: Full Screenshot

Inputs

Input requested data here

	Name	Symbol	Unit	Unchanging	Time Line [Months]							
	Name	Symbol	Unit	-	1	2	3	4	5	6	7	TOTAL
x	**Revenue per unit sold**	r_i										
	Product Family 1	r_1	Reais/ Unit									
	Product Family 2	r_2	Reais/ Unit									
	Product Family 3	r_3	Reais/ Unit									
	Product Family 4	r_4	Reais/ Unit									
	Product Family 5	r_5	Reais/ Unit									
	Product Family 6	r_6	Reais/ Unit									
x	**Materials cost**	g_i										
	Product Family 1	g_1	Reais/ Unit									
	Product Family 2	g_2	Reais/ Unit									
	Product Family 3	g_3	Reais/ Unit									
	Product Family 4	g_4	Reais/ Unit									
	Product Family 5	g_5	Reais/ Unit									
	Product Family 6	g_6	Reais/ Unit									
x	**Inventory Carrying Cost**	inv_i										
	Product Family 1	inv_1	Reais/ Unit									
	Product Family 2	inv_2	Reais/ Unit									
	Product Family 3	inv_3	Reais/ Unit									
	Product Family 4	inv_4	Reais/ Unit									
	Product Family 5	inv_5	Reais/ Unit									
	Product Family 6	inv_6	Reais/ Unit									
x	**Hiring cost**	h	Reais/ Employee									
x	**Firing cost**	f	Reais/ Employee									
x	**Workforce regular time cost - Regular Shift**	w	Reais/ (Employee * Month)									
x	**Workforce regular time cost - Night Shift**	w'	Reais/ (Employee * Month)									
x	**Workforce variable regular time cost - Saturday**	vw	Reais/ (Employee * Hour)									
x	**Workforce overtime cost - During the week (not during night time)**	o	Reais/ (Employee * Hour)									
x	**Workforce overtime cost - During the week (during night time)**	o'	Reais/ (Employee * Hour)									
x	**Workforce overtime cost - On Saturday**	o''	Reais/ (Employee * Hour)									
x	**Cycle Time**	c_i_j										
	Product Family 1 - Prodution Line 1	c_1_1	Hours/ Unit									
	Product Family 1 - Prodution Line 2	c_1_2	Hours/ Unit									
	Product Family 2 - Prodution Line 1	c_2_1	Hours/ Unit									
	Product Family 2 - Prodution Line 2	c_2_2	Hours/ Unit									
	Product Family 3 - Prodution Line 1	c_3_1	Hours/ Unit									
	Product Family 3 - Prodution Line 2	c_3_2	Hours/ Unit									
	Product Family 4 - Prodution Line 1	c_4_1	Hours/ Unit									
	Product Family 4 - Prodution Line 2	c_4_2	Hours/ Unit									
	Product Family 5 - Prodution Line 1	c_5_1	Hours/ Unit									
	Product Family 5 - Prodution Line 2	c_5_2	Hours/ Unit									
	Product Family 6 - Prodution Line 1	c_6_1	Hours/ Unit									
	Product Family 6 - Prodution Line 2	c_6_2	Hours/ Unit									
x	**Required workforce per Production Line**	rw_j										
	Prodution Line 1	rw_1	Employees									
	Production Line 2	rw_2	Employees									
x	**Demand**	d_i_t										
	Product 1	d_1_t	Units									
	Product 2	d_2_t	Units									
	Product 3	d_3_t	Units									
	Product 4	d_4_t	Units									
	Product 5	d_5_t	Units									
	Product 6	d_6_t	Units									
x	**Demand - Inferior Limit**	dinf_i_t										
	Product 1	dinf_1_t	Units									
	Product 2	dinf_2_t	Units									
	Product 3	dinf_3_t	Units									
	Product 4	dinf_4_t	Units									
	Product 5	dinf_5_t	Units									
	Product 6	dinf_6_t	Units									
x	**Regular Available Time - Per Shift (during the week)**	a_t	Hours/ Month									
x	**Regular Available Time - Per Shift (on Saturday)**	a''_t	Hours/ Month									
x	**Available Time for Overtime - Per Shift (during the week)**	exa_t	Hours/ Month									
x	**Available Time for Overtime - Per Shift (on Saturday)**	exa''_t	Hours/ Month									

Output Spreadsheet: Partial Screenshots

Gross Margin

	GROSS	Revenues	Materials cost	Inventory cost	Labor cost	Labor cost	Labor cost	Overtime labor	Overtime labor	Overtime labor	Hiring cost
t=1	-	-	-	-	-	-	-	-	-	-	-
t=2	-	-	-	-	-	-	-	-	-	-	-
t=3	-	-	-	-	-	-	-	-	-	-	-
t=4	-	-	-	-	-	-	-	-	-	-	-
t=5	-	-	-	-	-	-	-	-	-	-	-
t=6	-	-	-	-	-	-	-	-	-	-	-
t=7	-	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-	-	-

Production and Inventory Allocation

Product Family	Period	Regular Production during the week	Regular Production during the week	Regular Production on Saturday (1st,	Overtime Production during the week	Overtime Production during the week	Overtime Production on Saturday	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand	Demand Fulfilled [%]
F1	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on	Available Medium-Term Capacity: 1st and 2nd shifts	Available Medium-Term Capacity: 3rd shift during the	Available Medium-Term Capacity: 1st, 2nd and 3rd	Medium-Term Capacity Utilization Rate: 1st and 2nd	Medium-Term Capacity Utilization Rate: 3rd shift during	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd
L1 - Regular	t=1	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=2	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=3	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=4	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=5	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the	Available Medium-Term Capacity: Overtime during the week in the	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the	Medium-Term Capacity Utilization Rate: Overtime during the week in the	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=2	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=3	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=4	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	-	-	-
L1	t=2	-	-	-
L1	t=3	-	-	-
L1	t=4	-	-	-
L1	t=5	-	-	-
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	-	-	-
L2	t=2	-	-	-
L2	t=3	-	-	-
L2	t=4	-	-	-
L2	t=5	-	-	-
L2	t=6	-	-	-
L2	t=7	-	-	-

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	Inactive	Inactive	Inactive
L1	t=2	Inactive	Inactive	Inactive
L1	t=3	Inactive	Inactive	Inactive
L1	t=4	Inactive	Inactive	Inactive
L1	t=5	Inactive	Inactive	Inactive
L1	t=6	Inactive	Inactive	Inactive
L1	t=7	Inactive	Inactive	Inactive
L2	t=1	Inactive	Inactive	Inactive
L2	t=2	Inactive	Inactive	Inactive
L2	t=3	Inactive	Inactive	Inactive
L2	t=4	Inactive	Inactive	Inactive
L2	t=5	Inactive	Inactive	Inactive
L2	t=6	Inactive	Inactive	Inactive
L2	t=7	Inactive	Inactive	Inactive

Workforce Allocation

	Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
	t=1	-	-	-	-
	t=2	-	-	-	-
	t=3	-	-	-	-
	t=4	-	-	-	-
	t=5	-	-	-	-
	t=6	-	-	-	-
	t=7	-	-	-	-

Output Spreadsheet: Full Screenshot

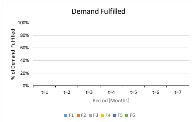
Outputs

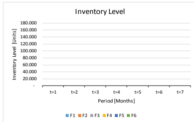
Gross Margin

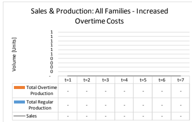
	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost	Overtime labor cost	Overtime labor cost	Hiring cost
t=1	-	-	-	-	-	-	-	-	-	-	-
t=2	-	-	-	-	-	-	-	-	-	-	-
t=3	-	-	-	-	-	-	-	-	-	-	-
t=4	-	-	-	-	-	-	-	-	-	-	-
t=5	-	-	-	-	-	-	-	-	-	-	-
t=6	-	-	-	-	-	-	-	-	-	-	-
t=7	-	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-	-	-

Production and Inventory Allocation

Product Family	Period	Regular Production during the week (1st and 2nd shifts)	Regular Production during the week (3rd shift)	Regular Production on Saturday (1st, 2nd and 3rd shifts)	Overtime Production during the week (daytime)	Overtime Production during the week (nighttime)	Overtime Production on Saturday	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand	Demand Fulfilled [%]
F1	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F1	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F2	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F3	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F4	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F5	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
F6	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=1	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=2	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=3	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=4	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=5	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=6	-	-	-	-	-	-	-	-	-	-	-	-	0%
All Families	t=7	-	-	-	-	-	-	-	-	-	-	-	-	0%

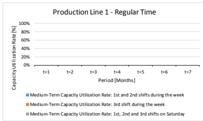


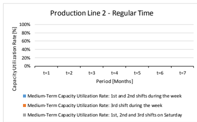




Capacity Analysis - Regular Time

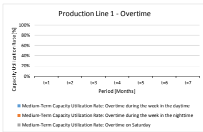
Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=2	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=3	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=4	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=5	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=1	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=2	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=3	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=4	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=5	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

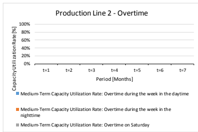




Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=2	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=3	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=4	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=2	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=3	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=4	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=5	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%





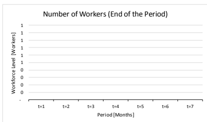
Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	-	-	-
L1	t=2	-	-	-
L1	t=3	-	-	-
L1	t=4	-	-	-
L1	t=5	-	-	-
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	-	-	-
L2	t=2	-	-	-
L2	t=3	-	-	-
L2	t=4	-	-	-
L2	t=5	-	-	-
L2	t=6	-	-	-
L2	t=7	-	-	-

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	Inactive	Inactive	Inactive
L1	t=2	Inactive	Inactive	Inactive
L1	t=3	Inactive	Inactive	Inactive
L1	t=4	Inactive	Inactive	Inactive
L1	t=5	Inactive	Inactive	Inactive
L1	t=6	Inactive	Inactive	Inactive
L1	t=7	Inactive	Inactive	Inactive
L2	t=1	Inactive	Inactive	Inactive
L2	t=2	Inactive	Inactive	Inactive
L2	t=3	Inactive	Inactive	Inactive
L2	t=4	Inactive	Inactive	Inactive
L2	t=5	Inactive	Inactive	Inactive
L2	t=6	Inactive	Inactive	Inactive
L2	t=7	Inactive	Inactive	Inactive

Workforce Allocation

	Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
	t=1	-	-	-	-
	t=2	-	-	-	-
	t=3	-	-	-	-
	t=4	-	-	-	-
	t=5	-	-	-	-
	t=6	-	-	-	-
	t=7	-	-	-	-



Core Spreadsheet: Partial Screenshots

Model

Indexes

i	i = 1, ..., N	*Product Type*
j	j = 1, ..., J	*Production Line*
s	s = 1, 2, 3	*Shift*
t	t = 1, ..., T	*Time Period*

Objective

Maximize Net Profit

		∑(r_i * ∑ (S_i_t))	∑(g_i * ∑(X_i_t + X'_	∑(inv_i * ∑(I_i_t))	w * ∑∑(W_j_t)	w' * ∑∑(W'_j_t)	vw * ∑ (rw_j * ∑ (c_	o * ∑ (rw_j * ∑ (c_i_	o' * ∑ (rw_j * ∑	o'' * ∑ (rw_j * ∑	h * ∑∑(H_j_t)	f * ∑∑(F_j_t)
	GROSS MARGIN	*Revenues*	*Materials cost*	*Inventory cost*	*Labor cost (Regul*	*Labor cost (Night*	*Labor cost (Satur*	*Overtime labor co*	*Overtime lab*	*Overtime lab*	*Hiring cost*	*Firing cost*
t=1	-	-	-	-	-	-	-	-	-	-	-	-
t=2	-	-	-	-	-	-	-	-	-	-	-	-
t=3	-	-	-	-	-	-	-	-	-	-	-	-
t=4	-	-	-	-	-	-	-	-	-	-	-	-
t=5	-	-	-	-	-	-	-	-	-	-	-	-
t=6	-	-	-	-	-	-	-	-	-	-	-	-
t=7	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-	-	-	-

Constants (Represented by small letters)

Name	Symbol	Unit
Revenue per unit sold	r_i	Reais/ Unit
Materials cost	g_i	Reais/ Unit
Inventory Carrying Cost	inv_i	Reais/ Unit
Hiring cost	h	Reais/ Employee
Firing cost	f	Reais/ Employee
Workforce regular time cost - Regular Shift	w	Reais/ (Employee * Month)
Workforce regular time cost - Night Shift	w'	Reais/ (Employee * Month)
Workforce variable regular time cost - Saturday	vw	Reais/ (Employee * Hour)
Workforce overtime cost - During the week (not during night time)	o	Reais/ (Employee * Hour)
Workforce overtime cost - During the week (during night time)	o'	Reais/ (Employee * Hour)
Workforce overtime cost - On Saturday	o''	Reais/ (Employee * Hour)

Cycle Time	c_i_j	Hours/ Unit
Required workforce per Production Line	rw_j	Employees
Demand	d_i_t	Units
Demand - Inferior Limit	dinf_i_t	Units
Regular Available Time - Per Shift (during the week)	a_t	Hours/ Month
Regular Available Time - Per Shift (on Saturday)	a''_t	Hours/ Month
Available Time for Overtime - Per Shift (during the week)	exa_t	Hours/ Month
Available Time for Overtime - Per Shift (on Saturday)	exa''_t	Hours/ Month

	r_1	r_2	r_3	r_4	r_5
Unchanging	-	-	-	-	-

	d_1_t	d_2_t	d_3_t	d_4_t	d_5_t
t=1	-	-	-	-	-
t=2	-	-	-	-	-
t=3	-	-	-	-	-
t=4	-	-	-	-	-
t=5	-	-	-	-	-
t=6	-	-	-	-	-
t=7	-	-	-	-	-

Variables (Represented by Capital Letters)

Name	Symbol	Unit
Quantity Sold	S_i_t	Units
Quantity Produced by Production Line (during the week - regular shifts)	X_i_j_t	Units
Quantity Produced (during the week - regular shifts)	X_i_t	Units
Quantity Produced by Production Line (during the week - night shift)	X'_i_j_t	Units
Quantity Produced (during the week - night shift)	X'_i_t	Units
Quantity Produced by production line (on Saturday - regular shifts)	X''_i_j_t	Units
Quantity Produced (on Saturday - regular shifts)	X''_i_t	Units
Extra Quantity Produced by Production Line (during the week - not during night time)	Y_i_j_t	Units
Extra Quantity Produced (during the week - not during night time)	Y_i_t	Units
Extra Quantity Produced by Production Line (during the week - during night time)	Y'_i_j_t	Units
Extra Quantity Produced (during the week - during night time)	Y'_i_t	Units
Extra Quantity Produced by Production Line (on Saturday)	Y''_i_j_t	Units
Extra Quantity Produced (on Saturday)	Y''_i_t	Units
Inventory	I_i_t	Units
Workforce Level - Regular shifts	W_j_t	Employees
Workforce Level - Night shift	W'_j_t	Employees
Hires	H_j_t	Employees
Layoffs	F_j_t	Employees
State of the Production Line	A_j_s_t	0 or 1

	S_1_t	S_2_t	S_3_t	S_4_t	S_5_t
t=1	-	-	-	-	-
t=2	-	-	-	-	-
t=3	-	-	-	-	-
t=4	-	-	-	-	-
t=5	-	-	-	-	-
t=6	-	-	-	-	-
t=7	-	-	-	-	-
TOTAL	-	-	-	-	-

Demand Constraints

Sales must be equal or lower than the demand in a certain time period

S_i_t <= d_i_t **For all i, t**

i=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
i=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

Sales must be equal or higher than the inferior limit (set by the decision maker) in a certain time period

dinf_i_t <= S_i_t **For all i, t**

i=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
i=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

Inventory Balance Constraints

Constraints that take into account the continuity of the inventory levels, which are susceptible to production and sales levels

I_i_t = I_i_t-1 + X_i_t + X'_i_t + X''_i_t + Y_i_t + Y'_i_t + Y''_i_t - S_i_t **For all i, t**

i=1	t=1	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-
i=2	t=1	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Capacity Constraints

Production in a certain time period must be within the Production Capacity for that time period

The production level considers if production line is active or inactive

∑ (c_i_j * X_i_j_t) <= a_t * (A_j_1_t + A_j_2_t) **For all j, t** **(Sum is related to i)**

j=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

∑ (c_i_j * X'_i_j_t) <= a_t * A_j_3_t **For all j, t** **(Sum is related to i)**

j=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

∑ (c_i_j * X''_i_j_t) <= a''_t * ∑ (A_j_s_t) **For all j, t** **(Sum is related to i, s)**

j=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

∑ (c_i_j * Y_i_j_t) <= exa_t * (1-A_j_2_t) * (1-A_j_3_t) * (A_j_1_t) **For all j, t** **(Sum is related to i)**

j=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

∑ (c_i_j * Y'_i_j_t) <= exa_t * (A_j_1_t) * (A_j_2_t) * (1-A_j_3_t) * (A_j_1_t + A_j_2_t) **For all j, t** **(Sum is related to i)**

j=1	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	t=1	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

∑ (c_i_j * Y''_i_j_t) <= exa''_t * ∑ (A_j_s_t) **For all j, t** **(Sum is related to I, s)**

j=1	**t=1**	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-
j=2	**t=1**	-	=<=	-
	t=2	-	=<=	-
	t=3	-	=<=	-
	t=4	-	=<=	-
	t=5	-	=<=	-
	t=6	-	=<=	-
	t=7	-	=<=	-

The production in each time period

X_i_t = ∑ (X_i_j_t) **For all i, t** **(Sum is related to j)**

i=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-
i=2	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

X'_i_t = ∑ (X'_i_j_t) **For all i, t** **(Sum is related to j)**

i=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-
i=2	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

X''_i_t = ∑ (X''_i_j_t) **For all i, t** **(Sum is related to j)**

i=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-
i=2	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Y_i_t = ∑ (Y_i_j_t) **For all i, t** **(Sum is related to j)**

i=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Y'_i_t = ∑ (Y'_i_j_t) **For all i, t** **(Sum is related to j)**

i=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Y''_i_t = ∑ (Y''_i_j_t) For all i, t (Sum is related to j)

i=1	t=1	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Workforce Balance Constraints

Variables related to hiring and firing workers and workforce level

W_j_t + W'_j_t = W_j_t-1 + W'_j_t-1 + H_j_t - F_j_t **For all j, t**

j=1	**t=1**	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

W_j_t = rw_j * (A_j_1_t + A_j_2_t) For all j, t (Sum is related to s)

j=1	t=1	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

W'_j_t = rw_j * A_j_3_t For all j, t (Sum is related to s)

j=1	t=1	-	=	-
	t=2	-	=	-
	t=3	-	=	-
	t=4	-	=	-
	t=5	-	=	-
	t=6	-	=	-
	t=7	-	=	-

Binary Constraints

Binary constraint showing if a production line is **A_j_s_t must be binary**

Non-Negativity Constraints

All variables must be >= 0

Integer Constraints

H_j_t and F_j_t must be integers **For all j, t**

Initiation Constraints

I_j_0, W_ j_ 0 and W'_ j_0 must be equal to zero **For all j**

APPENDIX E – VERIFICATION TESTS OF THE PRODUCTION-PLANNING MODEL

The verification tests were performed for both product categories – Easter eggs and *panettones*. However, with the intent of being succinct, this report presents the results of the developed model concerning Easter eggs.

Observation: the verification tests used What'sBEST!'s Global Solver in order to obtain Globally Optimal Solutions.

Workforce Allocation

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	17.124.808	23.592.062	4.984.829	-	810.000	486.000	85.500	-	-	10.925	90.000
t=2	12.736.291	18.711.322	4.758.550	-	810.000	243.000	66.000	-	12.600	24.880	-
t=3	14.284.519	20.579.322	5.085.653	-	810.000	243.000	82.500	-	12.600	61.050	-
t=4	20.371.642	26.507.708	5.002.666	-	810.000	243.000	66.000	-	12.000	2.400	-
t=5	16.874.674	23.657.401	5.666.744	-	810.000	243.000	47.384	-	13.200	2.400	-
t=6	5.492.105	9.339.666	3.159.343	87.881	405.000	-	867	-	11.471	3.000	-
t=7	6.666.658	9.339.666	2.399.707	-	202.500	-	3.000	6.300	-	1.500	-
TOTAL	93.550.698	131.727.147	31.057.492	87.881	4.657.500	1.458.000	351.251	6.300	61.871	106.155	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	137.493	-	137.493	137.493	-	137.493
F1	t=4	-	206.240	206.240	206.240	-	206.240
F1	t=5	274.988	-	274.988	274.988	-	274.988
F1	t=6	660.243	-	660.243	343.728	316.515	343.728
F1	t=7	27.213	-	27.213	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	25.983	90.756	116.740	116.740	-	116.740
F2	t=4	175.109	-	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	-	291.844	291.844	291.844	-	291.844
F2	t=7	291.844	-	291.844	291.844	-	291.844

F3	t=1	-	-	-	-	-	-
F3	t=2	28.007	26.471	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	217.915	-	217.915	217.915	-	217.915
F3	t=6	272.388	-	272.388	272.388	-	272.388
F3	t=7	153.907	118.481	272.388	272.388	-	272.388
F4	t=1	1.203.067	-	1.203.067	1.203.067	-	1.203.067
F4	t=2	583.503	378.947	962.450	962.450	-	962.450
F4	t=3	568.347	394.105	962.452	962.452	-	962.452
F4	t=4	901.820	60.632	962.451	962.451	-	962.451
F4	t=5	721.842	-	721.842	721.842	-	721.842
F4	t=6	0	-	0	-	0	-
F4	t=7	-	-	-	-	0	-
F5	t=1	941.518	100.801	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	1.487.757	-	1.487.757	833.854	653.903	833.854
F5	t=4	102.578	77.372	179.949	833.853	-	833.853
F5	t=5	310.771	314.622	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	907.975	136.709	1.044.684	907.975	-	907.975
F6	t=2	812.638	-	812.638	544.783	267.854	544.783
F6	t=3	276.930	-	276.930	544.784	-	544.784
F6	t=4	907.973	109.367	1.017.340	907.973	-	907.973
F6	t=5	726.382	-	726.382	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	3.052.559	237.509	3.290.069	3.153.360	-	3.153.360
All Families	t=2	2.385.116	405.418	2.790.534	2.522.680	267.854	2.522.680
All Families	t=3	2.605.467	484.862	3.090.329	2.704.280	653.903	2.704.280
All Families	t=4	2.250.914	453.610	2.704.524	3.249.060	-	3.249.060
All Families	t=5	2.485.378	314.622	2.800.000	2.800.000	-	2.800.000
All Families	t=6	932.631	291.844	1.224.475	907.960	316.515	907.960
All Families	t=7	472.964	118.481	591.445	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	33	317	158	48	100%	100%	70%
L1 - Regular	t=6	-	-	0	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L2 - Regular	t=2	302	-	32	302	-	32	100%	0%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	0	6	288	-	40	100%	0%	14%
L2 - Regular	t=7	151	-	20	151	-	20	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	3	-	-	30	0%	0%	11%
L1 - Overtime	t=2	-	-	12	-	-	24	0%	0%	48%
L1 - Overtime	t=3	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=4	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L2 - Overtime	t=2	-	84	16	-	84	16	0%	100%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	76	20	-	80	20	0%	96%	100%
L2 - Overtime	t=7	42	-	10	42	-	10	100%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	1	1	1
L2	t=2	1	1	-
L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	150	750
t=3	750	-	-	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	150	150

Available capacity as 10% of the current one

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	1.004.803	2.360.593	456.453	-	810.000	-	5.700	-	19.467	4.170	60.000
t=2	1.169.698	2.703.774	696.713	-	810.000	-	4.560	-	19.467	3.336	-
t=3	1.266.530	3.097.955	986.964	5.125	810.000	-	5.700	-	19.467	4.170	-
t=4	1.398.589	3.244.104	1.009.079	-	810.000	-	4.560	-	18.540	3.336	-
t=5	1.456.723	3.498.373	1.200.735	2.625	810.000	-	4.560	-	20.394	3.336	-
t=6	1.481.883	3.893.203	1.327.765	-	810.000	243.000	8.250	-	1.200	6.105	15.000
t=7	1.466.720	3.874.205	1.341.741	0	810.000	243.000	6.600	-	1.260	4.884	-
TOTAL	9.244.946	22.672.207	7.019.449	7.750	5.670.000	486.000	39.930	-	99.795	29.337	75.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	-	-	-	-	-	68.746
F1	t=3	-	-	-	-	-	137.493
F1	t=4	-	-	-	-	-	206.240
F1	t=5	-	-	-	-	-	274.988
F1	t=6	-	-	-	-	-	343.728
F1	t=7	-	-	-	-	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	9.681	48.689	58.370	58.370	-	58.370
F2	t=3	103.583	21.842	125.425	116.740	8.686	116.740
F2	t=4	108.339	58.084	166.423	175.109	-	175.109
F2	t=5	191.677	46.252	237.929	233.480	4.449	233.480
F2	t=6	248.067	39.328	287.395	291.844	-	291.844
F2	t=7	252.908	37.513	290.420	290.420	0	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	52.871	1.608	54.478	54.478	-	54.478
F3	t=3	78.015	30.942	108.957	108.957	-	108.957
F3	t=4	64.226	-	64.226	64.226	-	163.435
F3	t=5	14.582	12.557	27.139	27.139	-	217.915
F3	t=6	-	-	-	-	-	272.388
F3	t=7	0	-	0	-	0	272.388
F4	t=1	-	-	-	-	-	1.203.067

F4	t=2	-	-	-	-	-	962.450
F4	t=3	-	-	-	-	-	962.452
F4	t=4	-	-	-	-	-	962.451
F4	t=5	-	-	-	-	-	721.842
F4	t=6	0	-	0	-	0	-
F4	t=7	-	-	-	-	0	-
F5	t=1	207.166	62.924	270.091	270.091	-	1.042.318
F5	t=2	122.447	9.681	132.128	132.128	-	833.852
F5	t=3	-	-	-	-	-	833.854
F5	t=4	-	-	-	-	-	833.853
F5	t=5	-	-	-	-	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	-	-	-	-	-	907.975
F6	t=2	-	-	-	-	-	544.783
F6	t=3	-	-	-	-	-	544.784
F6	t=4	-	-	-	-	-	907.973
F6	t=5	-	-	-	-	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	207.166	62.924	270.091	270.091	-	3.153.360
All Families	t=2	184.999	59.977	244.976	244.976	-	2.522.680
All Families	t=3	181.598	52.784	234.382	225.696	8.686	2.704.280
All Families	t=4	172.565	58.084	230.649	239.335	-	3.249.060
All Families	t=5	206.260	58.809	265.069	260.619	4.449	2.800.000
All Families	t=6	248.067	39.328	287.395	291.844	0	907.960
All Families	t=7	252.908	37.513	290.420	290.420	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	30	-	4	30	-	4	100%	0%	100%
L1 - Regular	t=2	30	-	3	30	-	3	100%	0%	100%
L1 - Regular	t=3	30	-	4	30	-	4	100%	0%	100%
L1 - Regular	t=4	29	-	3	29	-	3	100%	0%	100%
L1 - Regular	t=5	32	-	3	32	-	3	100%	0%	100%
L1 - Regular	t=6	29	14	6	29	14	6	100%	100%	100%
L1 - Regular	t=7	30	15	5	30	15	5	100%	100%	100%

L2 - Regular	t=1	30	-	4	30	-	4	100%	0%	100%
L2 - Regular	t=2	30	-	3	30	-	3	100%	0%	100%
L2 - Regular	t=3	30	-	4	30	-	4	100%	0%	100%
L2 - Regular	t=4	29	-	3	29	-	3	100%	0%	100%
L2 - Regular	t=5	32	-	3	32	-	3	100%	0%	100%
L2 - Regular	t=6	29	-	4	29	-	4	100%	0%	100%
L2 - Regular	t=7	30	-	3	30	-	3	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	8	2	-	8	2	0%	100%	100%
L1 - Overtime	t=2	-	8	2	-	8	2	0%	100%	100%
L1 - Overtime	t=3	-	8	2	-	8	2	0%	100%	100%
L1 - Overtime	t=4	-	8	2	-	8	2	0%	100%	100%
L1 - Overtime	t=5	-	9	2	-	9	2	0%	100%	100%
L1 - Overtime	t=6	-	-	3	-	-	3	0%	0%	100%
L1 - Overtime	t=7	-	-	2	-	-	2	0%	0%	100%
L2 - Overtime	t=1	-	8	2	-	8	2	0%	100%	100%
L2 - Overtime	t=2	-	8	2	-	8	2	0%	100%	100%
L2 - Overtime	t=3	-	8	2	-	8	2	0%	100%	100%
L2 - Overtime	t=4	-	8	2	-	8	2	0%	100%	100%
L2 - Overtime	t=5	-	9	2	-	9	2	0%	100%	100%
L2 - Overtime	t=6	-	8	2	-	8	2	0%	100%	100%
L2 - Overtime	t=7	-	8	2	-	8	2	0%	100%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	-
L1	t=2	1	1	-
L1	t=3	1	1	-
L1	t=4	1	1	-
L1	t=5	1	1	-
L1	t=6	1	1	1
L1	t=7	1	1	1
L2	t=1	1	1	-
L2	t=2	1	1	-

L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	1	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	600	-	600
t=2	600	-	-	600
t=3	600	-	-	600
t=4	600	-	-	600
t=5	600	-	-	600
t=6	600	150	-	750
t=7	750	-	-	750

Available capacity as 30% of the current one

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	5.525.838	8.623.780	1.667.527	-	810.000	486.000	25.650	-	-	18.765	90.000
t=2	5.548.489	8.744.862	1.864.841	-	810.000	486.000	20.520	-	-	15.012	-
t=3	5.924.053	9.437.056	2.172.588	-	810.000	486.000	25.650	-	-	18.765	-
t=4	5.580.296	9.215.470	2.303.642	-	810.000	486.000	20.520	-	-	15.012	-
t=5	6.287.222	10.307.450	2.688.697	-	810.000	486.000	20.520	-	-	15.012	-
t=6	5.232.255	9.339.666	2.779.525	-	810.000	486.000	25.650	-	-	6.235	-
t=7	5.244.371	9.339.666	2.779.525	-	810.000	486.000	18.690	-	-	1.080	-
TOTAL	39.342.523	65.007.950	16.256.345	-	5.670.000	3.402.000	157.200	-	-	89.881	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	-	-	-	-	-	68.746
F1	t=3	-	-	-	-	-	137.493
F1	t=4	-	-	-	-	-	206.240
F1	t=5	-	-	-	-	-	274.988
F1	t=6	343.728	-	343.728	343.728	-	343.728
F1	t=7	343.728	-	343.728	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	116.740	-	116.740	116.740	-	116.740
F2	t=4	153.328	21.782	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	264.617	27.227	291.844	291.844	-	291.844
F2	t=7	291.844	-	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	201.510	16.405	217.915	217.915	-	217.915
F3	t=6	266.635	5.753	272.388	272.388	-	272.388
F3	t=7	255.983	16.405	272.388	272.388	-	272.388
F4	t=1	-	-	-	-	-	1.203.067

F4	t=2	-	-	-	-	-	962.450
F4	t=3	-	-	-	-	-	962.452
F4	t=4	-	-	-	-	-	962.451
F4	t=5	-	-	-	-	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-

F5	t=1	932.249	54.454	986.703	986.703	-	1.042.318
F5	t=2	779.765	43.563	823.328	823.328	-	833.852
F5	t=3	670.844	54.454	725.298	725.298	-	833.854
F5	t=4	500.935	21.782	522.717	522.717	-	833.853
F5	t=5	448.643	21.782	470.425	470.425	0	625.393
F5	t=6	-	-	-	-	0	-
F5	t=7	-	-	-	-	0	-

F6	t=1	-	-	-	-	-	907.975
F6	t=2	-	-	-	-	-	544.783
F6	t=3	-	-	-	-	-	544.784
F6	t=4	-	-	-	-	-	907.973
F6	t=5	-	-	-	-	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-

All Families	t=1	932.249	54.454	986.703	986.703	-	3.153.360
All Families	t=2	892.613	43.563	936.176	936.176	-	2.522.680
All Families	t=3	896.540	54.454	950.994	950.994	-	2.704.280
All Families	t=4	817.698	43.563	861.261	861.261	-	3.249.060
All Families	t=5	883.633	38.187	921.820	921.820	0	2.800.000
All Families	t=6	874.981	32.979	907.960	907.960	0	907.960
All Families	t=7	891.555	16.405	907.960	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	91	45	18	91	45	18	100%	100%	100%
L1 - Regular	t=2	91	45	14	91	45	14	100%	100%	100%
L1 - Regular	t=3	91	45	18	91	45	18	100%	100%	100%
L1 - Regular	t=4	86	43	14	86	43	14	100%	100%	100%
L1 - Regular	t=5	95	48	14	95	48	14	100%	100%	100%
L1 - Regular	t=6	86	43	18	86	43	18	100%	100%	100%
L1 - Regular	t=7	91	45	13	91	45	14	100%	100%	90%

L2 - Regular	t=1	91	45	18	91	45	18	100%	100%	100%
L2 - Regular	t=2	91	45	14	91	45	14	100%	100%	100%
L2 - Regular	t=3	91	45	18	91	45	18	100%	100%	100%
L2 - Regular	t=4	86	43	14	86	43	14	100%	100%	100%
L2 - Regular	t=5	95	48	14	95	48	14	100%	100%	100%
L2 - Regular	t=6	86	43	18	86	43	18	100%	100%	100%
L2 - Regular	t=7	91	45	14	91	45	14	100%	100%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	9	-	-	9	0%	0%	100%
L1 - Overtime	t=2	-	-	7	-	-	7	0%	0%	100%
L1 - Overtime	t=3	-	-	9	-	-	9	0%	0%	100%
L1 - Overtime	t=4	-	-	7	-	-	7	0%	0%	100%
L1 - Overtime	t=5	-	-	7	-	-	7	0%	0%	100%
L1 - Overtime	t=6	-	-	3	-	-	9	0%	0%	28%
L1 - Overtime	t=7	-	-	-	-	-	7	0%	0%	0%
L2 - Overtime	t=1	-	-	9	-	-	9	0%	0%	100%
L2 - Overtime	t=2	-	-	7	-	-	7	0%	0%	100%
L2 - Overtime	t=3	-	-	9	-	-	9	0%	0%	100%
L2 - Overtime	t=4	-	-	7	-	-	7	0%	0%	100%
L2 - Overtime	t=5	-	-	7	-	-	7	0%	0%	100%
L2 - Overtime	t=6	-	-	9	-	-	9	0%	0%	100%
L2 - Overtime	t=7	-	-	7	-	-	7	0%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	1	1	1
L1	t=7	1	1	1
L2	t=1	1	1	1
L2	t=2	1	1	1

L2	t=3	1	1	1
L2	t=4	1	1	1
L2	t=5	1	1	1
L2	t=6	1	1	1
L2	t=7	1	1	1

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	-	900
t=3	900	-	-	900
t=4	900	-	-	900
t=5	900	-	-	900
t=6	900	-	-	900
t=7	900	-	-	900

Available capacity as 60% of the current one

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	11.967.477	16.949.966	3.507.659	-	810.000	486.000	51.300	-	-	37.530	90.000
t=2	9.908.394	14.927.517	3.652.059	-	810.000	486.000	41.040	-	-	30.024	-
t=3	8.870.802	14.258.538	4.002.906	-	810.000	486.000	51.300	-	-	37.530	-
t=4	16.764.039	22.085.933	3.954.829	-	810.000	486.000	41.040	-	-	30.024	-
t=5	13.131.683	19.028.188	4.529.441	-	810.000	486.000	41.040	-	-	30.024	-
t=6	5.489.326	9.339.666	2.989.089	48.898	607.500	-	15.852	0	7.200	1.800	-
t=7	6.292.825	9.339.666	2.569.961	-	405.000	-	2.880	-	7.560	1.440	-
TOTAL	72.424.546	105.929.473	25.205.945	48.898	5.062.500	2.430.000	244.452	0	14.760	168.372	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	-	-	-	-	-	68.746
F1	t=3	-	-	-	-	-	137.493
F1	t=4	-	-	-	-	-	206.240
F1	t=5	-	-	-	-	-	274.988
F1	t=6	518.365	0	518.365	343.728	174.637	343.728
F1	t=7	169.091	-	169.091	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	7.832	108.908	116.740	116.740	-	116.740
F2	t=4	131.546	43.563	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	291.844	-	291.844	291.844	-	291.844
F2	t=7	110.332	181.513	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	152.294	65.620	217.915	217.915	-	217.915
F3	t=6	135.679	136.709	272.388	272.388	-	272.388
F3	t=7	272.388	-	272.388	272.388	-	272.388
F4	t=1	-	-	-	-	-	1.203.067

F4	t=2	-	-	-	-	-	962.450
F4	t=3	-	-	-	-	-	962.452
F4	t=4	-	-	-	-	-	962.451
F4	t=5	-	-	-	-	-	721.842
F4	t=6	-	0	0	-	0	-
F4	t=7	-	-	-	-	0	-
F5	t=1	987.864	54.454	1.042.318	1.042.318	-	1.042.318
F5	t=2	790.289	43.563	833.852	833.852	-	833.852
F5	t=3	833.854	-	833.854	833.854	-	833.854
F5	t=4	826.841	43.563	870.404	833.853	36.551	833.853
F5	t=5	588.842	-	588.842	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	660.249	82.025	742.274	701.262	-	907.975
F6	t=2	677.805	-	677.805	544.783	165.832	544.783
F6	t=3	661.389	-	661.389	346.396	480.826	544.784
F6	t=4	427.147	-	427.147	907.973	-	907.973
F6	t=5	658.883	19.644	678.527	658.883	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	1.648.113	136.479	1.784.592	1.743.580	-	3.153.360
All Families	t=2	1.580.942	43.563	1.624.505	1.491.483	165.832	2.522.680
All Families	t=3	1.612.031	108.908	1.720.939	1.405.946	480.826	2.704.280
All Families	t=4	1.548.969	87.126	1.636.095	2.080.369	36.551	3.249.060
All Families	t=5	1.633.500	85.264	1.718.764	1.735.671	-	2.800.000
All Families	t=6	945.888	136.709	1.082.597	907.960	174.637	907.960
All Families	t=7	551.810	181.513	733.323	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	181	91	36	181	91	36	100%	100%	100%
L1 - Regular	t=2	181	91	29	181	91	29	100%	100%	100%
L1 - Regular	t=3	181	91	36	181	91	36	100%	100%	100%
L1 - Regular	t=4	173	86	29	173	86	29	100%	100%	100%
L1 - Regular	t=5	190	95	29	190	95	29	100%	100%	100%
L1 - Regular	t=6	86	-	10	86	-	12	100%	0%	80%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

L2 - Regular	t=1	181	91	36	181	91	36	100%	100%	100%
L2 - Regular	t=2	181	91	29	181	91	29	100%	100%	100%
L2 - Regular	t=3	181	91	36	181	91	36	100%	100%	100%
L2 - Regular	t=4	173	86	29	173	86	29	100%	100%	100%
L2 - Regular	t=5	190	95	29	190	95	29	100%	100%	100%
L2 - Regular	t=6	173	-	24	173	-	24	100%	0%	100%
L2 - Regular	t=7	181	-	19	181	-	19	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	18	-	-	18	0%	0%	100%
L1 - Overtime	t=2	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=3	-	-	18	-	-	18	0%	0%	100%
L1 - Overtime	t=4	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=5	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=6	0	-	0	-	-	6	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	18	-	-	18	0%	0%	100%
L2 - Overtime	t=2	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=3	-	-	18	-	-	18	0%	0%	100%
L2 - Overtime	t=4	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=5	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=6	-	48	12	-	48	12	0%	100%	100%
L2 - Overtime	t=7	-	50	10	-	50	10	0%	100%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	1	-
L1	t=7	-	-	-
L2	t=1	1	1	1
L2	t=2	1	1	1

L2	t=3	1	1	1
L2	t=4	1	1	1
L2	t=5	1	1	1
L2	t=6	1	1	-
L2	t=7	1	1	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	-	900
t=3	900	-	-	900
t=4	900	-	-	900
t=5	900	-	-	900
t=6	900	-	450	450
t=7	450	-	150	300

Available capacity as 60% of the current one in addition to limit inferior for the fulfillment of the demand for F4

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	11.383.989	16.198.734	3.339.915	-	810.000	486.000	51.300	-	-	37.530	90.000
t=2	10.065.859	14.950.788	3.517.864	-	810.000	486.000	41.040	-	-	30.024	-
t=3	11.943.237	17.169.491	3.841.424	-	810.000	486.000	51.300	-	-	37.530	-
t=4	12.434.770	17.656.532	3.854.697	-	810.000	486.000	41.040	-	-	30.024	-
t=5	12.480.591	18.269.674	4.422.018	-	810.000	486.000	41.040	-	-	30.024	-
t=6	5.489.326	9.339.666	2.989.089	48.898	607.500	-	15.852	-	7.200	1.800	-
t=7	6.292.825	9.339.666	2.569.961	-	405.000	-	2.880	0	7.560	1.440	-
TOTAL	70.090.598	102.924.550	24.534.969	48.898	5.062.500	2.430.000	244.452	0	14.760	168.372	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	-	-	-	-	-	68.746
F1	t=3	-	-	-	-	-	137.493
F1	t=4	-	-	-	-	-	206.240
F1	t=5	-	-	-	-	-	274.988
F1	t=6	518.365	-	518.365	343.728	174.637	343.728
F1	t=7	-	169.091	169.091	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	116.740	-	116.740	116.740	-	116.740
F2	t=4	175.109	-	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	291.844	0	291.844	291.844	-	291.844
F2	t=7	291.844	-	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	82.025	26.932	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	152.294	65.620	217.915	217.915	-	217.915
F3	t=6	135.679	136.709	272.388	272.388	-	272.388
F3	t=7	237.348	35.040	272.388	272.388	-	272.388

F4	t=1	240.613	-	240.613	240.613	-	1.203.067
F4	t=2	192.490	-	192.490	192.490	-	962.450
F4	t=3	192.490	-	192.490	192.490	-	962.452
F4	t=4	109.137	83.353	192.490	192.490	-	962.451
F4	t=5	144.368	-	144.368	144.368	-	721.842
F4	t=6	0	0	0	-	0	-
F4	t=7	-	-	-	-	0	-
F5	t=1	987.864	54.454	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	981.049	-	981.049	833.854	147.195	833.854
F5	t=4	666.074	20.583	686.657	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	515.576	-	515.576	556.589	-	907.975
F6	t=2	529.258	-	529.258	484.882	109.996	544.783
F6	t=3	379.695	82.025	461.720	544.784	-	544.784
F6	t=4	449.800	-	449.800	449.800	-	907.973
F6	t=5	544.551	-	544.551	544.551	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	1.744.054	54.454	1.798.508	1.839.521	-	3.153.360
All Families	t=2	1.668.448	-	1.668.448	1.624.072	109.996	2.522.680
All Families	t=3	1.751.999	108.957	1.860.956	1.796.825	147.195	2.704.280
All Families	t=4	1.563.555	103.937	1.667.492	1.814.687	-	3.249.060
All Families	t=5	1.700.086	65.620	1.765.707	1.765.707	-	2.800.000
All Families	t=6	945.888	136.709	1.082.597	907.960	174.637	907.960
All Families	t=7	529.192	204.131	733.323	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	181	91	36	181	91	36	100%	100%	100%
L1 - Regular	t=2	181	91	29	181	91	29	100%	100%	100%
L1 - Regular	t=3	181	91	36	181	91	36	100%	100%	100%
L1 - Regular	t=4	173	86	29	173	86	29	100%	100%	100%
L1 - Regular	t=5	190	95	29	190	95	29	100%	100%	100%
L1 - Regular	t=6	86	-	10	86	-	12	100%	0%	80%

L1 - Regular	t=7	0	-	0	-	-	-	0%	0%	0%
L2 - Regular	t=1	181	91	36	181	91	36	100%	100%	100%
L2 - Regular	t=2	181	91	29	181	91	29	100%	100%	100%
L2 - Regular	t=3	181	91	36	181	91	36	100%	100%	100%
L2 - Regular	t=4	173	86	29	173	86	29	100%	100%	100%
L2 - Regular	t=5	190	95	29	190	95	29	100%	100%	100%
L2 - Regular	t=6	173	-	24	173	-	24	100%	0%	100%
L2 - Regular	t=7	181	-	19	181	-	19	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	18	-	-	18	0%	0%	100%
L1 - Overtime	t=2	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=3	-	-	18	-	-	18	0%	0%	100%
L1 - Overtime	t=4	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=5	-	-	14	-	-	14	0%	0%	100%
L1 - Overtime	t=6	-	-	-	-	-	6	0%	0%	0%
L1 - Overtime	t=7	0	-	0	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	18	-	-	18	0%	0%	100%
L2 - Overtime	t=2	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=3	-	-	18	-	-	18	0%	0%	100%
L2 - Overtime	t=4	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=5	-	-	14	-	-	14	0%	0%	100%
L2 - Overtime	t=6	-	48	12	-	48	12	0%	100%	100%
L2 - Overtime	t=7	-	50	10	-	50	10	0%	100%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	1	-
L1	t=7	-	-	-
L2	t=1	1	1	1

L2	t=2	1	1	1
L2	t=3	1	1	1
L2	t=4	1	1	1
L2	t=5	1	1	1
L2	t=6	1	1	-
L2	t=7	1	1	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	-	900
t=3	900	-	-	900
t=4	900	-	-	900
t=5	900	-	-	900
t=6	900	-	450	450
t=7	450	-	150	300

Inventory Level – Scenario 1

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	26.014.875	42.065.822	14.568.523	-	810.000	486.000	85.500	-	-	10.925	90.000
t=2	19.688.578	33.652.551	12.769.974	-	810.000	243.000	66.000	-	12.600	2.400	-
t=3	21.488.627	36.075.095	13.401.278	-	810.000	243.000	82.500	-	12.600	37.090	-
t=4	29.174.660	43.342.460	12.987.961	-	810.000	243.000	66.000	-	12.000	48.840	-
t=5	23.300.016	37.352.000	12.936.000	-	810.000	243.000	47.384	-	13.200	2.400	-
t=6	6.466.969	12.112.186	5.001.598	48.898	405.000	-	6.000	-	721	3.000	-
t=7	8.307.354	12.112.186	3.387.953	0	405.000	-	2.880	-	7.560	1.440	-
TOTAL	134.441.078	216.712.302	75.053.286	48.898	4.860.000	1.458.000	356.264	-	58.681	106.095	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	137.493	-	137.493	137.493	-	137.493
F1	t=4	-	206.240	206.240	206.240	-	206.240
F1	t=5	274.988	-	274.988	274.988	-	274.988
F1	t=6	424.350	94.015	518.365	343.728	174.637	343.728
F1	t=7	169.091	0	169.091	343.728	0	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	116.740	-	116.740	116.740	-	116.740
F2	t=4	102.504	72.605	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	291.844	-	291.844	291.844	-	291.844
F2	t=7	139.374	152.471	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	217.915	-	217.915	217.915	-	217.915
F3	t=6	272.388	-	272.388	272.388	-	272.388
F3	t=7	250.515	21.873	272.388	272.388	-	272.388
F4	t=1	1.203.067	-	1.203.067	1.203.067	-	1.203.067

F4	t=2	962.450	-	962.450	962.450	-	962.450
F4	t=3	962.452	-	962.452	962.452	-	962.452
F4	t=4	962.451	-	962.451	962.451	-	962.451
F4	t=5	327.737	394.105	721.842	721.842	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-
F5	t=1	951.562	90.756	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	805.060	28.794	833.854	833.854	-	833.854
F5	t=4	708.077	125.775	833.853	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	900.410	273.418	1.173.828	907.975	-	907.975
F6	t=2	558.319	344.220	902.539	544.783	241.384	544.783
F6	t=3	485.796	397.554	883.351	544.784	437.813	544.784
F6	t=4	470.160	-	470.160	907.973	-	907.973
F6	t=5	726.382	-	726.382	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	3.055.039	364.174	3.419.213	3.153.360	-	3.153.360
All Families	t=2	2.536.215	344.220	2.880.435	2.522.680	241.384	2.522.680
All Families	t=3	2.616.498	426.348	3.042.846	2.704.280	437.813	2.704.280
All Families	t=4	2.406.627	404.620	2.811.247	3.249.060	-	3.249.060
All Families	t=5	2.405.895	394.105	2.800.000	2.800.000	-	2.800.000
All Families	t=6	988.582	94.015	1.082.597	907.960	174.637	907.960
All Families	t=7	558.979	174.344	733.323	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	33	317	158	48	100%	100%	70%
L1 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

L2 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L2 - Regular	t=2	302	-	32	302	-	32	100%	0%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	-	40	288	-	40	100%	0%	100%
L2 - Regular	t=7	181	-	19	181	-	19	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	3	-	-	30	0%	0%	11%
L1 - Overtime	t=2	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=3	-	-	18	-	-	30	0%	0%	59%
L1 - Overtime	t=4	-	-	24	-	-	24	0%	0%	100%
L1 - Overtime	t=5	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L2 - Overtime	t=2	-	84	16	-	84	16	0%	100%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	5	20	-	80	20	0%	6%	100%
L2 - Overtime	t=7	-	50	10	-	50	10	0%	100%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	1	1	1
L2	t=2	1	1	-

L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	1	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	150	750
t=3	750	-	-	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	-	300

Inventory Allocation – Scenario 2

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	24.812.030	39.922.366	13.826.187	-	810.000	243.000	82.500	-	12.600	61.050	75.000
t=2	18.700.909	33.652.551	13.771.202	-	810.000	243.000	66.000	-	12.600	48.840	-
t=3	21.570.075	36.075.095	13.325.678	8.609	810.000	243.000	82.500	-	12.600	22.633	-
t=4	29.810.916	43.342.460	12.351.704	-	810.000	243.000	66.000	-	12.000	48.840	-
t=5	22.944.006	37.352.000	13.226.954	-	810.000	243.000	66.000	-	13.200	48.840	-
t=6	5.751.711	12.112.186	5.754.476	-	405.000	-	6.000	-	12.000	3.000	-
t=7	9.788.997	12.112.186	2.054.750	-	202.500	-	1.440	3.780	-	720	-
TOTAL	133.378.644	214.568.846	74.310.950	8.609	4.657.500	1.215.000	370.440	3.780	75.000	233.923	75.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	156.798	318.316	475.114	68.746	406.367	68.746
F1	t=3	-	-	-	137.493	268.874	137.493
F1	t=4	-	-	-	206.240	62.634	206.240
F1	t=5	212.353	-	212.353	274.988	-	274.988
F1	t=6	343.728	-	343.728	343.728	-	343.728
F1	t=7	325.538	18.189	343.728	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	291.849	-	291.849	116.740	175.109	116.740
F2	t=4	-	-	-	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	298.066	242.017	540.083	291.844	248.239	291.844
F2	t=7	43.606	-	43.606	291.844	-	291.844
F3	t=1	-	0	0	-	0	-
F3	t=2	51.527	54.684	106.211	54.478	51.732	54.478
F3	t=3	197.541	23.118	220.660	108.957	163.435	108.957
F3	t=4	-	-	-	163.435	-	163.435
F3	t=5	109.367	234.159	343.526	217.915	125.611	217.915
F3	t=6	316.177	45.570	361.747	272.388	214.970	272.388
F3	t=7	-	57.418	57.418	272.388	-	272.388
F4	t=1	884.751	318.316	1.203.067	1.203.067	-	1.203.067

F4	t=2	962.450	-	962.450	962.450	-	962.450
F4	t=3	993.200	-	993.200	962.452	30.747	962.452
F4	t=4	931.704	-	931.704	962.451	-	962.451
F4	t=5	721.842	-	721.842	721.842	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-
F5	t=1	951.562	90.756	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	579.736	254.118	833.854	833.854	-	833.854
F5	t=4	833.853	-	833.853	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	701.726	227.848	929.575	747.296	-	907.975
F6	t=2	508.328	102.836	611.164	544.783	-	544.783
F6	t=3	499.215	-	499.215	544.784	-	544.784
F6	t=4	634.555	364.557	999.112	907.973	-	907.973
F6	t=5	668.896	72.911	741.807	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	2.538.039	636.920	3.174.960	2.992.681	0	3.153.360
All Families	t=2	2.571.325	475.836	3.047.160	2.522.680	458.100	2.522.680
All Families	t=3	2.561.540	277.236	2.838.776	2.704.280	638.165	2.704.280
All Families	t=4	2.400.111	364.557	2.764.668	3.249.060	62.634	3.249.060
All Families	t=5	2.571.331	307.070	2.878.402	2.800.000	125.611	2.800.000
All Families	t=6	957.971	287.586	1.245.557	907.960	463.209	907.960
All Families	t=7	369.144	75.607	444.751	907.960	-	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	48	317	158	48	100%	100%	100%
L1 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

L2 - Regular	t=1	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=2	302	-	32	302	-	32	100%	0%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	-	40	288	-	40	100%	0%	100%
L2 - Regular	t=7	91	-	10	91	-	10	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=2	-	-	24	-	-	24	0%	0%	100%
L1 - Overtime	t=3	-	-	10	-	-	30	0%	0%	34%
L1 - Overtime	t=4	-	-	24	-	-	24	0%	0%	100%
L1 - Overtime	t=5	-	-	24	-	-	24	0%	0%	100%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=2	-	84	16	-	84	16	0%	100%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	80	20	-	80	20	0%	100%	100%
L2 - Overtime	t=7	25	-	5	25	-	5	100%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	1	1	-
L2	t=2	1	1	-

L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	750	-	750
t=2	750	-	-	750
t=3	750	-	-	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	150	150

Use of Overtime – Baseline Scenario

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	16.574.827	22.630.018	4.771.041	-	810.000	243.000	82.500	-	12.600	61.050	75.000
t=2	12.891.370	18.711.322	4.678.428	-	810.000	243.000	66.000	-	12.600	9.923	-
t=3	14.127.031	20.579.322	5.243.141	-	810.000	243.000	82.500	-	12.600	61.050	-
t=4	20.434.051	26.507.708	4.925.300	-	810.000	243.000	66.000	-	12.000	17.357	-
t=5	16.874.674	23.657.401	5.666.744	-	810.000	243.000	47.384	-	13.200	2.400	-
t=6	5.457.608	9.339.666	3.186.627	94.194	405.000	-	1.237	-	12.000	3.000	-
t=7	6.694.843	9.339.666	2.372.423	-	202.500	-	2.400	6.300	-	1.200	-
TOTAL	93.054.403	130.765.104	30.843.705	94.194	4.657.500	1.215.000	348.021	6.300	75.000	155.980	75.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	-	137.493	137.493	137.493	-	137.493
F1	t=4	206.240	-	206.240	206.240	-	206.240
F1	t=5	274.988	-	274.988	274.988	-	274.988
F1	t=6	379.821	303.158	682.979	343.728	339.252	343.728
F1	t=7	-	4.476	4.476	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	-	58.370	58.370	58.370	-	58.370
F2	t=3	56.235	60.504	116.740	116.740	-	116.740
F2	t=4	175.109	-	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	291.844	-	291.844	291.844	-	291.844
F2	t=7	164.785	127.059	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	-	54.478	54.478	54.478	-	54.478
F3	t=3	40.602	68.354	108.957	108.957	-	108.957
F3	t=4	109.367	54.068	163.435	163.435	-	163.435
F3	t=5	217.915	0	217.915	217.915	-	217.915
F3	t=6	226.818	45.570	272.388	272.388	-	272.388
F3	t=7	256.851	15.537	272.388	272.388	-	272.388
F4	t=1	724.547	211.285	935.833	935.833	-	1.203.067

F4	t=2	962.450	-	962.450	962.450	-	962.450
F4	t=3	962.452	-	962.452	962.452	-	962.452
F4	t=4	962.451	-	962.451	962.451	-	962.451
F4	t=5	661.211	60.632	721.842	721.842	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-
F5	t=1	914.824	127.495	1.042.318	1.042.318	-	1.042.318
F5	t=2	845.909	183.581	1.029.490	833.852	195.638	833.852
F5	t=3	614.755	23.461	638.216	833.854	-	833.854
F5	t=4	591.836	242.017	833.853	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	825.722	150.608	976.329	907.975	-	907.975
F6	t=2	647.678	-	647.678	544.783	102.895	544.783
F6	t=3	825.722	227.762	1.053.483	544.784	474.884	544.784
F6	t=4	433.088	-	433.088	907.973	-	907.973
F6	t=5	525.876	217.061	742.936	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	2.465.092	489.388	2.954.480	2.886.126	-	3.153.360
All Families	t=2	2.524.784	296.429	2.821.213	2.522.680	298.533	2.522.680
All Families	t=3	2.499.767	517.574	3.017.341	2.704.280	474.884	2.704.280
All Families	t=4	2.478.091	296.085	2.774.176	3.249.060	-	3.249.060
All Families	t=5	2.538.862	277.692	2.816.554	2.800.000	-	2.800.000
All Families	t=6	898.484	348.728	1.247.212	907.960	339.252	907.960
All Families	t=7	421.637	147.071	568.708	907.960	-	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	33	317	158	48	100%	100%	70%
L1 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

L2 - Regular	t=1	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=2	302	-	32	302	-	32	100%	0%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	-	8	288	-	40	100%	0%	21%
L2 - Regular	t=7	151	-	16	151	-	16	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=2	-	-	4	-	-	24	0%	0%	16%
L1 - Overtime	t=3	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=4	-	-	8	-	-	24	0%	0%	32%
L1 - Overtime	t=5	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=2	-	84	16	-	84	16	0%	100%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	80	20	-	80	20	0%	100%	100%
L2 - Overtime	t=7	42	-	8	42	-	8	100%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	1	1	-
L2	t=2	1	1	-

L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	750	-	750
t=2	750	-	-	750
t=3	750	-	-	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	150	150

Use of Overtime – Increased Overtime Costs

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	17.099.110	23.592.062	4.984.829	-	810.000	486.000	85.500	-	-	36.623	90.000
t=2	12.550.432	18.711.322	4.854.090	-	810.000	486.000	7.200	-	-	3.600	-
t=3	14.295.839	20.579.322	5.074.401	-	810.000	243.000	80.483	-	12.600	3.000	-
t=4	20.455.929	26.507.708	4.918.379	-	810.000	243.000	66.000	-	12.000	2.400	-
t=5	16.874.674	23.657.401	5.666.744	-	810.000	243.000	47.384	-	13.200	2.400	-
t=6	5.457.608	9.339.666	3.186.627	94.194	405.000	0	6.000	-	7.237	3.000	-
t=7	6.694.843	9.339.666	2.372.423	-	202.500	-	2.400	6.300	-	1.200	-
TOTAL	93.428.435	131.727.147	31.057.492	94.194	4.657.500	1.701.000	294.966	6.300	45.037	52.223	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	137.493	-	137.493	137.493	-	137.493
F1	t=4	-	206.240	206.240	206.240	-	206.240
F1	t=5	-	274.988	274.988	274.988	-	274.988
F1	t=6	607.190	75.789	682.979	343.728	339.252	343.728
F1	t=7	4.476	-	4.476	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	-	116.740	116.740	116.740	-	116.740
F2	t=4	97.737	77.372	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	145.879	145.965	291.844	291.844	-	291.844
F2	t=7	140.584	151.261	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	5.489	103.468	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	146.293	71.621	217.915	217.915	-	217.915
F3	t=6	272.388	-	272.388	272.388	-	272.388
F3	t=7	272.388	-	272.388	272.388	-	272.388
F4	t=1	1.076.801	126.266	1.203.067	1.203.067	-	1.203.067

F4	t=2	871.503	90.947	962.450	962.450	-	962.450
F4	t=3	1.015.430	-	1.015.430	962.452	52.977	962.452
F4	t=4	848.842	60.632	909.474	962.451	-	962.451
F4	t=5	721.842	-	721.842	721.842	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-
F5	t=1	1.042.318	-	1.042.318	1.042.318	-	1.042.318
F5	t=2	1.285.033	-	1.285.033	833.852	451.182	833.852
F5	t=3	382.672	-	382.672	833.854	-	833.854
F5	t=4	833.853	-	833.853	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	907.975	-	907.975	907.975	-	907.975
F6	t=2	544.783	-	544.783	544.783	-	544.783
F6	t=3	959.858	50.434	1.010.292	544.784	460.643	544.784
F6	t=4	447.330	-	447.330	907.973	-	907.973
F6	t=5	726.382	-	726.382	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	3.027.094	126.266	3.153.360	3.153.360	-	3.153.360
All Families	t=2	2.882.914	90.947	2.973.862	2.522.680	451.182	2.522.680
All Families	t=3	2.500.942	270.642	2.771.583	2.704.280	513.621	2.704.280
All Families	t=4	2.391.197	344.243	2.735.439	3.249.060	-	3.249.060
All Families	t=5	2.453.391	346.609	2.800.000	2.800.000	-	2.800.000
All Families	t=6	1.025.457	221.754	1.247.212	907.960	339.252	907.960
All Families	t=7	417.448	151.261	568.708	907.960	-	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	-	302	151	48	100%	100%	0%
L1 - Regular	t=3	302	151	58	302	151	60	100%	100%	97%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	33	317	158	48	100%	100%	70%
L1 - Regular	t=6	-	0	0	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

L2 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L2 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	-	40	288	-	40	100%	0%	100%
L2 - Regular	t=7	151	-	16	151	-	16	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	3	-	-	30	0%	0%	11%
L1 - Overtime	t=2	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=3	-	-	-	-	-	30	0%	0%	0%
L1 - Overtime	t=4	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L2 - Overtime	t=2	-	-	24	-	-	24	0%	0%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	48	20	-	80	20	0%	60%	100%
L2 - Overtime	t=7	42	-	8	42	-	8	100%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-
L2	t=1	1	1	1
L2	t=2	1	1	1

L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	-	900
t=3	900	-	150	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	150	150

Production Line Prioritization

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	17.696.758	23.592.062	4.984.829	-	405.000	243.000	153.000	-	-	64.475	45.000
t=2	12.867.030	18.711.322	5.073.892	-	405.000	243.000	122.400	-	-	-	-
t=3	14.762.170	20.579.322	5.089.875	-	405.000	243.000	79.277	-	-	-	-
t=4	21.103.953	26.507.708	4.745.505	-	405.000	243.000	10.250	-	-	-	-
t=5	17.405.060	23.657.401	5.604.342	-	405.000	243.000	-	-	-	-	-
t=6	6.213.767	9.339.666	2.779.525	-	202.500	-	23.874	-	-	-	-
t=7	6.352.127	9.339.666	2.779.525	-	202.500	-	5.514	-	-	-	-
TOTAL	96.400.866	131.727.147	31.057.492	-	2.430.000	1.215.000	394.315	-	-	64.475	45.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	137.493	-	137.493	137.493	-	137.493
F1	t=4	206.240	-	206.240	206.240	-	206.240
F1	t=5	274.988	-	274.988	274.988	-	274.988
F1	t=6	343.728	-	343.728	343.728	-	343.728
F1	t=7	343.728	-	343.728	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	116.740	-	116.740	116.740	-	116.740
F2	t=4	175.109	-	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	291.844	-	291.844	291.844	-	291.844
F2	t=7	291.844	-	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	54.478	-	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	217.915	-	217.915	217.915	-	217.915
F3	t=6	272.388	-	272.388	272.388	-	272.388
F3	t=7	272.388	-	272.388	272.388	-	272.388
F4	t=1	1.203.067	-	1.203.067	1.203.067	-	1.203.067

F4	t=2	962.450	-	962.450	962.450	-	962.450
F4	t=3	962.452	-	962.452	962.452	-	962.452
F4	t=4	962.451	-	962.451	962.451	-	962.451
F4	t=5	721.842	-	721.842	721.842	-	721.842
F4	t=6	-	-	-	-	-	-
F4	t=7	-	-	-	-	-	-
F5	t=1	1.042.318	-	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	833.854	-	833.854	833.854	-	833.854
F5	t=4	833.853	-	833.853	833.853	-	833.853
F5	t=5	625.393	-	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	832.056	177.393	1.009.449	907.975	-	907.975
F6	t=2	939.281	-	939.281	544.783	394.497	544.783
F6	t=3	722.439	-	722.439	544.784	572.152	544.784
F6	t=4	360.882	-	360.882	907.973	25.061	907.973
F6	t=5	701.321	-	701.321	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	3.077.441	177.393	3.254.834	3.153.360	-	3.153.360
All Families	t=2	2.917.177	-	2.917.177	2.522.680	394.497	2.522.680
All Families	t=3	2.881.935	-	2.881.935	2.704.280	572.152	2.704.280
All Families	t=4	2.701.969	-	2.701.969	3.249.060	25.061	3.249.060
All Families	t=5	2.774.939	-	2.774.939	2.800.000	-	2.800.000
All Families	t=6	907.960	-	907.960	907.960	-	907.960
All Families	t=7	907.960	-	907.960	907.960	-	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	605	302	120	605	302	120	100%	100%	100%
L1 - Regular	t=2	605	302	96	605	302	96	100%	100%	100%
L1 - Regular	t=3	605	302	62	605	302	120	100%	100%	52%
L1 - Regular	t=4	576	288	8	576	288	96	100%	100%	8%
L1 - Regular	t=5	634	317	-	634	317	96	100%	100%	0%
L1 - Regular	t=6	288	-	19	288	-	40	100%	0%	47%
L1 - Regular	t=7	302	-	4	302	-	32	100%	0%	14%

L2 - Regular	t=1	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=2	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=3	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=4	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=5	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=6	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	33	-	-	60	0%	0%	56%
L1 - Overtime	t=2	-	-	-	-	-	48	0%	0%	0%
L1 - Overtime	t=3	-	-	-	-	-	60	0%	0%	0%
L1 - Overtime	t=4	-	-	-	-	-	48	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	48	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	20	0%	0%	0%
L1 - Overtime	t=7	-	-	-	84	-	16	0%	0%	0%
L2 - Overtime	t=1	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=2	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=3	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=4	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=5	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	1	-
L1	t=7	1	-	-
L2	t=1	-	-	-
L2	t=2	-	-	-

L2	t=3	-	-	-
L2	t=4	-	-	-
L2	t=5	-	-	-
L2	t=6	-	-	-
L2	t=7	-	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	450	-	450
t=2	450	-	-	450
t=3	450	-	-	450
t=4	450	-	-	450
t=5	450	-	-	450
t=6	450	-	300	150
t=7	150	-	-	150

APPENDIX F – PRODUCTION-PLANNING MODELS APPLIED TO THE COMPANY

Easter Eggs

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	17.124.808	23.592.062	4.984.829	-	810.000	486.000	85.500	-	-	10.925	90.000
t=2	12.736.291	18.711.322	4.758.550	-	810.000	243.000	66.000	-	12.600	24.880	-
t=3	14.284.519	20.579.322	5.085.653	-	810.000	243.000	82.500	-	12.600	61.050	-
t=4	20.371.642	26.507.708	5.002.666	-	810.000	243.000	66.000	-	12.000	2.400	-
t=5	16.874.674	23.657.401	5.666.744	-	810.000	243.000	47.384	-	13.200	2.400	-
t=6	5.492.105	9.339.666	3.159.343	87.881	405.000	-	867	-	11.471	3.000	-
t=7	6.666.658	9.339.666	2.399.707	-	202.500	-	3.000	6.300	-	1.500	-
TOTAL	93.550.698	131.727.147	31.057.492	87.881	4.657.500	1.458.000	351.251	6.300	61.871	106.155	90.000

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	-	-	-	-	-	-
F1	t=2	68.746	-	68.746	68.746	-	68.746
F1	t=3	137.493	-	137.493	137.493	-	137.493
F1	t=4	-	206.240	206.240	206.240	-	206.240
F1	t=5	274.988	-	274.988	274.988	-	274.988
F1	t=6	660.243	-	660.243	343.728	316.515	343.728
F1	t=7	27.213	-	27.213	343.728	-	343.728
F2	t=1	-	-	-	-	-	-
F2	t=2	58.370	-	58.370	58.370	-	58.370
F2	t=3	25.983	90.756	116.740	116.740	-	116.740
F2	t=4	175.109	-	175.109	175.109	-	175.109
F2	t=5	233.480	-	233.480	233.480	-	233.480
F2	t=6	-	291.844	291.844	291.844	-	291.844
F2	t=7	291.844	-	291.844	291.844	-	291.844
F3	t=1	-	-	-	-	-	-
F3	t=2	28.007	26.471	54.478	54.478	-	54.478
F3	t=3	108.957	-	108.957	108.957	-	108.957
F3	t=4	163.435	-	163.435	163.435	-	163.435
F3	t=5	217.915	-	217.915	217.915	-	217.915
F3	t=6	272.388	-	272.388	272.388	-	272.388
F3	t=7	153.907	118.481	272.388	272.388	-	272.388

F4	t=1	1.203.067	-	1.203.067	1.203.067	-	1.203.067
F4	t=2	583.503	378.947	962.450	962.450	-	962.450
F4	t=3	568.347	394.105	962.452	962.452	-	962.452
F4	t=4	901.820	60.632	962.451	962.451	-	962.451
F4	t=5	721.842	-	721.842	721.842	-	721.842
F4	t=6	0	-	0	-	0	-
F4	t=7	-	-	-	-	0	-
F5	t=1	941.518	100.801	1.042.318	1.042.318	-	1.042.318
F5	t=2	833.852	-	833.852	833.852	-	833.852
F5	t=3	1.487.757	-	1.487.757	833.854	653.903	833.854
F5	t=4	102.578	77.372	179.949	833.853	-	833.853
F5	t=5	310.771	314.622	625.393	625.393	-	625.393
F5	t=6	-	-	-	-	-	-
F5	t=7	-	-	-	-	-	-
F6	t=1	907.975	136.709	1.044.684	907.975	-	907.975
F6	t=2	812.638	-	812.638	544.783	267.854	544.783
F6	t=3	276.930	-	276.930	544.784	-	544.784
F6	t=4	907.973	109.367	1.017.340	907.973	-	907.973
F6	t=5	726.382	-	726.382	726.382	-	726.382
F6	t=6	-	-	-	-	-	-
F6	t=7	-	-	-	-	-	-
All Families	t=1	3.052.559	237.509	3.290.069	3.153.360	-	3.153.360
All Families	t=2	2.385.116	405.418	2.790.534	2.522.680	267.854	2.522.680
All Families	t=3	2.605.467	484.862	3.090.329	2.704.280	653.903	2.704.280
All Families	t=4	2.250.914	453.610	2.704.524	3.249.060	-	3.249.060
All Families	t=5	2.485.378	314.622	2.800.000	2.800.000	-	2.800.000
All Families	t=6	932.631	291.844	1.224.475	907.960	316.515	907.960
All Families	t=7	472.964	118.481	591.445	907.960	0	907.960

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	144	48	288	144	48	100%	100%	100%
L1 - Regular	t=5	317	158	33	317	158	48	100%	100%	70%

L1 - Regular	t=6	-	-	0	-	-	-	0%	0%	0%
L1 - Regular	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Regular	t=1	302	151	60	302	151	60	100%	100%	100%
L2 - Regular	t=2	302	-	32	302	-	32	100%	0%	100%
L2 - Regular	t=3	302	-	40	302	-	40	100%	0%	100%
L2 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%
L2 - Regular	t=5	317	-	32	317	-	32	100%	0%	100%
L2 - Regular	t=6	288	0	6	288	-	40	100%	0%	14%
L2 - Regular	t=7	151	-	20	151	-	20	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	3	-	-	30	0%	0%	11%
L1 - Overtime	t=2	-	-	12	-	-	24	0%	0%	48%
L1 - Overtime	t=3	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=4	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=5	-	-	-	-	-	24	0%	0%	0%
L1 - Overtime	t=6	-	-	-	-	-	-	0%	0%	0%
L1 - Overtime	t=7	-	-	-	-	-	-	0%	0%	0%
L2 - Overtime	t=1	-	-	30	-	-	30	0%	0%	100%
L2 - Overtime	t=2	-	84	16	-	84	16	0%	100%	100%
L2 - Overtime	t=3	-	84	20	-	84	20	0%	100%	100%
L2 - Overtime	t=4	-	80	16	-	80	16	0%	100%	100%
L2 - Overtime	t=5	-	88	16	-	88	16	0%	100%	100%
L2 - Overtime	t=6	-	76	20	-	80	20	0%	96%	100%
L2 - Overtime	t=7	42	-	10	42	-	10	100%	0%	100%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	1
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	1
L1	t=5	1	1	1
L1	t=6	-	-	-
L1	t=7	-	-	-

L2	t=1	1	1	1
L2	t=2	1	1	-
L2	t=3	1	1	-
L2	t=4	1	1	-
L2	t=5	1	1	-
L2	t=6	1	1	-
L2	t=7	1	-	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	900	-	900
t=2	900	-	150	750
t=3	750	-	-	750
t=4	750	-	-	750
t=5	750	-	-	750
t=6	750	-	450	300
t=7	300	-	150	150

Panettones

Gross Margin

	GROSS MARGIN	Revenues	Materials cost	Inventory cost	Labor cost (Regular Shifts)	Labor cost (Night Shift)	Labor cost (Saturday)	Overtime labor cost (During the week, not night time)	Overtime labor cost (During the week, night time)	Overtime labor cost (Saturday)	Hiring cost
t=1	65.779	669.384	188.650	9.956	337.500	-	42.500	-	-	-	25.000
t=2	537.265	1.494.261	314.795	-	337.500	202.500	51.000	-	-	38.700	12.500
t=3	482.529	1.487.225	352.571	-	337.500	202.500	63.750	-	-	48.375	-
t=4	277.779	945.002	226.792	-	337.500	-	34.000	-	-	18.930	-
TOTAL	1.363.353	4.595.872	1.082.808	9.956	1.350.000	405.000	191.250	-	-	106.005	37.500

Production and Inventory Allocation

Product Family	Period	Total Regular Production	Total Overtime Production	Total Production	Sales	Inventory	Demand
F1	t=1	2.226	-	2.226	2.226	-	2.226
F1	t=2	7.792	-	7.792	7.792	-	7.792
F1	t=3	17.808	-	17.808	17.808	-	17.808
F1	t=4	16.697	-	16.697	16.697	-	16.697
F2	t=1	40.956	-	40.956	40.956	-	40.956
F2	t=2	92.170	-	92.170	92.170	-	92.170
F2	t=3	51.198	-	51.198	51.198	-	51.198
F2	t=4	20.482	-	20.482	20.482	-	20.482
F3	t=1	124.160	-	124.160	41.668	82.492	41.668
F3	t=2	10.637	-	10.637	93.128	-	98.982
F3	t=3	30.776	14.630	45.407	45.407	-	57.297
F3	t=4	10.419	-	10.419	10.419	-	10.419
F4	t=1	10.686	-	10.686	2.671	8.015	2.671
F4	t=2	-	-	-	8.015	-	8.015
F4	t=3	-	21.370	21.370	21.370	-	21.370
F4	t=4	21.372	-	21.372	21.372	-	21.372
F5	t=1	9.019	-	9.019	9.019	-	9.019
F5	t=2	13.721	4.320	18.041	18.041	-	18.041
F5	t=3	36.077	-	36.077	36.077	-	36.077
F5	t=4	24.948	2.113	27.061	27.061	-	27.061
All Families	t=1	187.046	-	187.046	96.540	90.506	96.540
All Families	t=2	124.320	4.320	128.640	219.146	-	225.000
All Families	t=3	135.860	36.000	171.860	171.860	-	183.750

All Families	t=4	93.917	2.113	96.030	96.030	-	96.030

Capacity Analysis - Regular Time

Production Line	Period	Utilized Capacity: 1st and 2nd shifts during the week	Utilized Capacity: 3rd shift during the week	Utilized Capacity: 1st, 2nd and 3rd shifts on Saturday	Available Medium-Term Capacity: 1st and 2nd shifts during the week	Available Medium-Term Capacity: 3rd shift during the week	Available Medium-Term Capacity: 1st, 2nd and 3rd shifts on Saturday	Medium-Term Capacity Utilization Rate: 1st and 2nd shifts during the week	Medium-Term Capacity Utilization Rate: 3rd shift during the week	Medium-Term Capacity Utilization Rate: 1st, 2nd and 3rd shifts on Saturday
L1 - Regular	t=1	302	-	40	302	-	40	100%	0%	100%
L1 - Regular	t=2	302	151	48	302	151	48	100%	100%	100%
L1 - Regular	t=3	302	151	60	302	151	60	100%	100%	100%
L1 - Regular	t=4	288	-	32	288	-	32	100%	0%	100%

Capacity Analysis - OverTime

Production Line	Period	Utilized Capacity: Overtime during the week in the daytime	Utilized Capacity: Overtime during the week in the nighttime	Utilized Capacity: Overtime on Saturday	Available Medium-Term Capacity: Overtime during the week in the daytime	Available Medium-Term Capacity: Overtime during the week in the nighttime	Available Medium-Term Capacity: Overtime on Saturday	Medium-Term Capacity Utilization Rate: Overtime during the week in the daytime	Medium-Term Capacity Utilization Rate: Overtime during the week in the nighttime	Medium-Term Capacity Utilization Rate: Overtime on Saturday
L1 - Overtime	t=1	-	-	-	-	84	20	0%	0%	0%
L1 - Overtime	t=2	-	-	24	-	-	24	0%	0%	100%
L1 - Overtime	t=3	-	-	30	-	-	30	0%	0%	100%
L1 - Overtime	t=4	-	-	12	-	80	16	0%	0%	73%

Capacity Analysis - Production Line Activity

Production Line	Period	1st Shift	2nd Shift	3rd Shift
L1	t=1	1	1	-
L1	t=2	1	1	1
L1	t=3	1	1	1
L1	t=4	1	1	-

Workforce Allocation

Period	Number of Workers (Beginning of the Period)	Hires	Layoffs	Number of Workers (End of the Period)
t=1	-	250	-	250
t=2	250	125	-	375
t=3	375	-	-	375
t=4	375	-	125	250

APPENDIX G – DIAGRAMS FOR COMPANY A'S FUTURE INFORMATION FLOW

SIPOC Diagram: Long-term Forecasting after the Implementation of the Models

This module remains unaltered after the implementation of the line-balancing and production-planning models.

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•Historical monthly sales of Easter eggs and *panettones* from the past three years •Roadshow with contractors and retailers	Long-term Forecasting	•3-year monthly demand forecast •Preliminary sales mix	Operations Department

SIPOC Diagram: Demand Management after the Implementation of the Models

The implementation of the developed models does not change this module.

Supplier	Input	Process	Output	Customer
Sales & Marketing Department	•Real client orders	Demand Management	•Updated demand forecasting for the year in question •Updated sales mix	Operations Department

SIPOC Diagram: Capacity Planning after the Implementation of the Models

The line-balancing model aims at supporting the assessment of the operational performance of the production lines in their yearly rebalance, and, to this end, it reproduces the company's existing production lines. Hence, the capacity planning module basically remains the same after its implementation.

The sole modification of the module is the input from the operations department, which is currently the production lines' cycle times for each product family (these cycle times are obtained during the production time of the previous years). With the implementation of the model, the input from the operations department is the workstations' cycle time in order for the model to reproduce each workstation accordingly.

Supplier	**Input**	**Process**	**Output**	**Customer**
Sales & Marketing Department	•3-year demand forecast		•Re-balanced production configuration	Purchasing Department
Operations Department	•Workstations' cycle time for each product family	Capacity Planning	•Production lines' cycle time for each product family and item (in the case an equipment has just been added to the line)	Operations Department
Purchasing Department	•Possible equipment alternatives			

Furthermore, the line-balancing model can provide the subsequent (lower-hierarchy) planning modules with robust and unlagged inputs about the production lines. This is especially true when an equipment has been added to the production line, and the cycle times for each product family and item (needed for the running of the aggregate and the MPS/ RCCP modules respectively) change.

SIPOC Diagram: Aggregate Planning after the Implementation of the Models

Currently, Company A does not conduct the aggregate planning. Therefore, the implementation of the production-planning model requires brand new information flows (inputs and outputs) between departments (suppliers and customers).

Supplier	**Input**	**Process**	**Output**	**Customer**
HR Department	•Workforce cost (regular, overtime, hiring and firing)	Aggregate Planning	•Staffing plan (timing of hires and layoffs, as well as the usage of shifts and overtime)	HR Department
Sales & Marketing Department	•Aggregate demand for each product family •Average price for product families		•Beginning of the production period •Production and inventory goals	Operations Department
Operations Department	•Production lines' cycle time for each product family •Required workers per production line •Available production time			
Purchasing Department	•Materials cost			
Finance Department	•Inventory cost			

SIPOC Diagram: MPS after the Implementation of the Models

The implementation of the models does not require any real change in this module. Currently, this module works with the long-term demand forecast provided by the Sales & Marketing department. With the implementation of the production-planning model, it works with the production goals provided by the model, which are cost-aware and capacity-feasible.

Supplier	Input	Process	Output	Customer
Operations Department	•Production Goals	Master Production Scheduling	•Disaggregated production goals in terms of products	Operations Department
Sales & Marketing Department	•Sales mix			

SIPOC Diagram: RCCP after the Implementation of the Models

The implementation of the line-balancing and the production-planning models change the robustness of this module's inputs (consequently, its outputs as well).

The line-balancing model provides reliable information about the production lines' cycle time for each product item when an equipment has been added to the production line (which is different than the cycle time obtained during the production control of the previous year).

The production-planning model indicates the timing of hires and layoffs, as well as the usage of shifts and overtime, providing information about the short/ medium-term capacity for the RCCP.

Supplier	Input	Process	Output	Customer
Operations Department	•Disaggregated production goals in terms of product items •Staffing Plan •Production lines' cycle time for each product item	Rough Cut Capacity Planning	•Feasible Master Schedule Plan	Operations Department

SIPOC Diagram: MRP after the implementation of the Models

The implementation of the models does not require any modification in this module.

<table>
<tr><th>Supplier</th><th>Input</th><th>Process</th><th>Output</th><th>Customer</th></tr>
<tr><td rowspan="2">Operations Department</td><td rowspan="2">•Feasible Master Schedule Plan
•Bill of materials
•Inventory status
•Production times</td><td rowspan="2">Materials Requirements Planning</td><td>•Manufacturing jobs</td><td>Operations Department</td></tr>
<tr><td>•Purchasing orders</td><td>Purchasing Department</td></tr>
</table>