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“Hierarchically integrating the production planning and scheduling to optimize the production planning process of a beverage company“

Vrumona
zet de toon
in de markt

Master thesis

Industrial Engineering and Management

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Executive summary

This research assesses the currently used production planning process of Vrumona, with the aim to improve the process. As the trade-off between production- and inventory costs is not known, Vrumona expects that the production planning process can be improved.

Currently, the production planning software Advanced Planning (AP) constructs the production plan. The production plan is used by the production planner to construct the production schedule. AP uses cost priorities and takes the constraints of the Syrup- and Packaging department into account to construct the production plan. This production planning approach does not use the internally available inventory capacity as a restriction, making this planning approach not account for higher inventory costs when soft drinks need to be stored externally. The constructed production plans cannot fulfil the customer demand. Therefore, the production planner modifies the production plans, with the aim to meet the customer demand.

The purpose of this research is to structurally improve the production planning approach and minimize the total production- and inventory costs, while maintaining the current service level of 99.5%. For this research we define the following research question:

> *How can Vrumona structurally improve their production planning approach to minimize the production- and inventory costs, while maintaining a customer service level of 99.5%?*

This research focuses on two of the nine production lines. Production line 4 is selected, as this production line has limited available production capacity. Production line 10 is selected, as this production line has excessive production capacity. Production line 4 bottles 20cl glass bottles for the Out of Home industry and production line 10 bottles 1.5 litre cartons for the Retail industry. With these production lines, we can show how the planning approaches perform for both types of production capacities.

To show how the production planning process can be improved, this research developed three planning approaches for the production planning process of the Supply Chain Planning department. The research compares these planning approaches with the currently used planning approach AP. The planning approaches focus on the tactical production planning problem. In order to compare these approaches, it is important to define how much changeover time the constructed production plans use. Therefore, we optimize the production sequence per production week of the production plans with a scheduling algorithm (SA) that uses sequence dependent changeover times.

One of the developed planning approaches uses the algorithm of AP software, and uses real changeover- and inventory costs rather than the currently used cost priorities. The other two planning approaches use an Integrated Production Planning and Scheduling (IPPS) approach to construct a production plan. These IPPS approaches take product families into account, which make the approaches willing to combine soft drinks of the same product family in the same production week. This provides a better approximation of used changeover time in a week. Moreover, these planning approaches take into account the internal inventory capacity level, which defines when soft drinks need to be stored externally for higher storage costs. In addition, these planning approaches can extend the available production capacity, resulting in higher costs. The research compares the following four planning approaches:

Current (AP/SA): *Software Advanced Planning (AP)*
The current planning approach uses the Advanced Planning software, which uses cost priorities.

Alternative 1 (MILP/SA): *Mixed Integer Linear Programming (MILP) approach*
This planning approach uses the mathematical optimisation technique that attempts to construct a production plan within the defined constraints with the lowest costs.

Alternative 2 (AS/SA): *Adaptive Search (AS) and Simulated Annealing (SA) approach*
This planning approach constructs an initial production plan (AS), where the lot-sizes are computed with the Economic Production Quantity (EPQ). The Simulated Annealing (SA) algorithm optimizes the initial production plan to lower the total costs.

Alternative 3 (AP/SA real costs): *Software Advanced Planning (AP) with actual costs*
This planning approach uses AP, but uses actual changeover- and inventory costs instead of the currently used cost priorities.

The experimental structure of the research assesses the four planning approaches on weeks of the season with high demand and on weeks of the season with low demand. This results in the selection of four experiment weeks in January 2012, in which the demand is low, and four experiment weeks in April 2012, in which the demand is high. With these eight experiment weeks, we show how the four planning approaches perform for both seasons.

The experimental results of the production planning approaches show that the planning approach "MILP/SA" outperforms the other planning approaches on cost reduction and customer service level. In comparison with the other planning approaches, the planning approach "MILP/SA" accomplishes a cost reduction of 41% for production line 4 and a cost reduction of 27% for production line 10, on the tactical planning level. Also, this planning approach constructs production plans that achieve a customer service level of 100% for the experiment weeks. The other planning approaches do not achieve an average customer service level higher than 99.5% over the experiment weeks. In addition, the production plans of the planning approach "MILP/SA" result in the lowest amount of externally stored soft drinks, which decreases the handling activities of the Logistic department. This research proposes to use the planning approach "MILP/SA" for the tactical production planning problem.

Comparing the planning approach "MILP/SA" with the current planning approach on the total used changeover time per week, the planning approach "MILP/SA" uses 4% more changeover time. This negative effect on the total used changeover time, is due to the fact that this planning approach uses on average one changeover extra in the weeks of April in 2012. In addition, the production plans of the planning approach "MILP/SA" uses smaller production lot-sizes in comparison with the production plans of the current planning approach. We conclude that the smaller production lot-sizes do not affect the syrup quality, because the minimum production lot-sizes secure the syrup quality.

The current software Advanced Planning utilizes the same mathematical technique as the planning approach "MILP/SA". Therefore we recommend, translating the new knowledge on the production planning process into the AP software. Implementing this planning approach for the other production lines also results in a cost reduction on the tactical planning level. In order to use this planning approach for the other production lines, the costs need to be defined for the soft drinks of these production lines.

Preface

I wrote this paper for my graduation at the University of Twente. After completing my Bachelor Industrial Engineering and Management with a Bachelor thesis in the area of inventory management, I became more interested in the optimization and innovative aspects of production and logistic processes. Therefore, I chose the Master Production and Logistic Management to get more acquainted with the mathematical optimization of these processes and to obtain more knowledge on the innovative ideas in this research field. To graduate from this Master, I chose a Master assignment at a production company. In the search for an innovative production company, this resulted in my choice for Vrumona.

I thank Vrumona for providing the opportunity to perform this Master graduation project. This graduation project has extended my knowledge about the fusion of science and practice. I experienced Vrumona as a very inspiring work environment and I really enjoyed my time at Vrumona. I thank my colleagues, Klaas-Jan, Bas, Rob, Edwin, Bernice, and Iris for their support, input, and feedback. In particular, I thank my supervisors of Vrumona, Klaas-Jan and Bas, for our valuable meetings, their supervision, and their support.

I thank my supervisors of the University of Twente, Dr. Ir. J.M.J. Schutten and Dr. P.C. Schuur for their critical feedback on my thesis and support to improve the planning algorithms. My supervisors supported me in structuring my ideas to provide an accessible report.

Finally, I thank my girlfriend, friends, and family for their support and effort to provide feedback on my Master thesis.

Utrecht, 23-August-2013,

Jorrit ter Horst

Contents

Abbreviations

AP : Advanced Planning software (Infor)
ASI : Advanced Scheduling software (Infor)
BAS : Daily production schedule
DvP : Demand for Planning
OoH : Out of Home
MRP : Material Requirement Planning
ERP : Enterprise Resource Program
SAP : ERP-system of Vrumona
SCP : Supply Chain Planning
WACC : Weighted Average Cost of Capital
CLSP : Capacitated Lot-Sizing Problem
MILP : Mixed Linear Integer Programming
AS : Adaptive Search
SA : Simulated Annealing
ABC : Activity Based Costing
TOC : Theory of Constraints
ROI : Return On Investment
FGI : Finished Good Inventory
PKE : Project Kaizen Engineering
KPI : Key Performance Indicator
OPI : Operation Performance Indicator
JIT : Just In Time
WIP : Work in Process
RM : Raw materials for syrups
SR : Produced syrups
PM : Raw materials for packaging
GP : Finished goods

1 Introduction

This report aims to improve the production planning approach of Vrumona. Vrumona expects that the production planning approach can be improved, since the trade-off between production cost and inventory costs is not known. To search for improvement opportunities, we analyse the current situation of the Supply Chain Planning (SCP) department as well as the cost structure.

One year ago, the production planner made both the production planning and the production schedule arbitrarily, with the support of a software tool that graphically shows the production time in a Gantt-chart. Although this software supported the intuitive decision making of the production planner to specify the production lot-sizes, the production week, and the production sequence within a week, it did not account for the trade-off between production- and inventory costs.

Currently, the planning software Advanced Planning (AP) constructs the production plan, which is used by the production planner to construct the production schedule. The AP software uses cost priorities and takes the constraints of the Syrup- and Packaging department into account to construct a production plan. The constructed production plans do not fulfil all customer demand. Therefore, the production planner modifies the production plan with the aim to meet the customer demand.

This chapter provides a general description of Vrumona and a description of its parent company Heineken in Section 1.1. Section 1.2 provides the project formulation, which contains the research delineation, causes of the research problem, and the problem definition. Section 1.3 defines the outline of the research.

1.1 Company profile

To provide some general understanding about the company of research, this section provides a brief description of Vrumona. This section also describes the influences of the parent company Heineken N.V on the activities of Vrumona.

1.1.1 Vrumona B.V.

Vrumona is a Dutch soft drink manufacturer with a wide product range. The foundation of Vrumona was established 65 years ago, out of a partnership of 30 small soft drink manufacturers. The major part of the soft drinks is produced for the Dutch market (Retail & Out of Home) and the minor part of the soft drinks is produced for export. In 1953, the Heineken and Amstel breweries joined the partnership of the small soft drink manufacturers. In this year, the company name was changed to Vrumona. From the year 1968, Vrumona became a subsidiary of Heineken N.V.

Vrumona bottles more than 300 different soft drinks with a strong focus on product innovations to be a step ahead of their competitors. Not only in soft drink innovations and soft drink promotions Vrumona is ahead of their competitors, in the mid-fifties Vrumona developed the first family bottle for soft drinks together with the research organization TNO. In addition, Vrumona was the first-mover of the PET Returnable Bottle (PRB) in the Netherlands.

Figure 1: Major brands of Vrumona

Currently, the soft drink portfolio consists of three brand categories: Vrumona's own brands, licensed brands, and co-packing brands, of which the major brands are represented in Figure 1. Vrumona produces, distributes, and does the marketing for their own brands and the licensed brands. For the co-packing brands, Vrumona solely bottles the soft drinks.

The production facility and the head office of Vrumona are both located in Bunnik, the Netherlands. Vrumona published the following mission statement (Vrumona, 2013):

> *"Vrumona wants to be a reliable, service-oriented and innovative organization, where the consumer plays a central role, obviously in accordance with Heineken global standards."*

As mentioned in the mission statement, Vrumona wants to be a reliable, service-oriented and innovative organization, where the Heineken N.V. defines the global standards for the company. Beside the measures of the mission statement, Vrumona focuses on cost reduction, which is together with the stated customer service level of 99.5% the main driver of this research.

1.1.2 Heineken Group

Heineken N.V. is the parent company of Vrumona, with its head office located in Amsterdam, the Netherlands. In 1864, Heineken started as a small local beer brewer in Amsterdam and has evolved into a worldwide operating organization owning many premium brands. Heineken has become one of the largest beer brewers in the world with more than 130 breweries in over 70 countries.

The Heineken head office imposes the general strategy for the subsidiaries and attempts to shift from a locally organized perspective to a centralized perspective. Therewith, subsidiaries are supported with knowhow and standards from the Board of Directors in Amsterdam. Heineken defines the general company strategy and safety standards of Vrumona. In this sense, Vrumona is restricted by Heineken. However, Vrumona has an autonomous decision making structure on the tactical and operational levels.

1.2 Project formulation

This section describes the project formulation, whereby we delineate the research field, define the causes of the research problem, and define the research problem. This section starts with the research motivation.

Vrumona wants to be a reliable and service-oriented organization, with its focus on cost reduction. It is expected that the production planning approach can be improved, since the trade-off between production- and inventory costs is not known. Therefore, this research focuses on costs related to production planning and opportunities to improve the production planning approach by maintaining the current service level. This research is part of an improvement project for production planning, which Vrumona has started in 2012.

One year ago, the production planner made both the production planning and the production schedule manually, with the support of software that graphically shows the production time in a Gantt-chart. Although this tool supported the intuitive decision-making of the production planner, it did not make a trade-off between the production- and inventory costs. The production planner anticipated on the inventory coverage of soft drinks to define production lot-sizes and production weeks. For the production schedule, the production planner attempts to minimize the total changeover time for a production week.

Using the manually performed planning approach, the Supply Chain Planning (SCP) department realized that they did not fully utilize the capabilities of the software tool. Therefore, the decision was made to further explore the capabilities of the software tool. An improvement project for the production planning process in 2012 resulted in the use of the planning algorithm of the Advanced Planning (AP) software. Together with the software engineers of Heineken, the SCP department defined the input parameters to optimize the production plan, which specifies the production lot-sizes and production week of the soft drinks, for the forthcoming 26 weeks. The SCP department arbitrarily defined the input parameters values. It is arguable whether these parameters and parameter values result in production plans with the lowest total costs.

Currently, the production planner manually constructs the production schedule for the planned production lot-sizes for the first four weeks, because the production sequence rules has several exceptions and every production changeover has its own changeover time. It is preferred to start the production with low taste soft drinks at the beginning of a week, follow an ascending taste, and at the end of a week the soft drink with the strongest taste. This ascending taste sequence leads to the shortest total changeover time for a production week. Each production line has its own production sequence rules and exceptions on these rules. The sequence dependent changeover times, the preferred production sequence, and the production sequence rules guide the production planner to make a near optimal production schedule.

The production planning process shows improvement opportunities on cost reduction, since the constructed production plans with the AP software does not fulfil all customer demand and the input parameters and parameter values are arbitrarily defined. Vrumona does not use the full potential of the planning algorithm AP and does not know the trade-off between the production- and inventory costs. This makes it difficult for the production planner to understand how AP defines the production lot-sizes and how the values of the input parameters should be defined to make a production plan with the lowest total cost, without violating the customer service level constraint.

In addition, Vrumona uses a make-to-stock philosophy for the bottling of soft drinks. To serve the customer demand on time, the company operates five days a week 24 hours a day. The available workforce restricts the production capacity per production line, but the production capacity can be extended against higher labour cost. Although not all production lines experience the production capacity as a constraining factor, the production capacity is an important constraint for the tactical production planning problem.

In conclusion, the production planner solves the production scheduling problem almost to optimality, because the sequence dependent changeover times, preferred production sequence, and production sequence rules guide the production planner to construct a near optimal production schedule. An improvement to the production schedule does not result in the desired cost reduction and is not the main focus of this research. However, the tactical production planning shows opportunities for improvement, because the production planner needs to modify the constructed production plan to serve the customer demand. Therefore, we focus on the tactical production planning problem. This research analyses several production planning approaches to find a novel planning approach to reducing the total costs and maintaining the current customer service level.

1.2.1 Delineating the research

For this research, we delineate the research to the tactical production planning problem. We want to know how Vrumona can optimize the current production planning approach to minimize total costs, while maintaining the current customer service level. To define the improvement opportunities, it is important to know that several departments relate to the production planning and decisions on the operation and strategic planning levels affect the tactical production plan. Therefore, the tactical production planning problem cannot be seen as a stand-alone improvable problem that can directly lead to a cost reduction.

The AP software needs input from several departments, such as information of the Sales- and Production departments to construct a production plan. The Sales department copes with demand uncertainty, increasing when looking further into the future. The Packaging department copes with uncertain production events, such as machine breakdowns and production speed losses that affect the production speed of a production line. Both uncertainties can affect production lot-sizes and production weeks of soft drinks in the production plan.

With the focus on cost reduction and customer service level, we also delineate the research scope to syrup- and packaging production. Therefore, we exclude the supply of raw materials and delivery of soft drinks to the customer from the research scope. This research takes into account the demand uncertainty and we assume that Vrumona can deliver the produced soft drinks directly from stock. Furthermore, we assume that all materials are available before they need to be processed. Figure 2 shows the process flow from suppliers towards customers and the research scope. This research aims to deliver a production planning approach that incorporates the trade-off between production- and inventory costs. In addition, production lot-sizes and production weeks of the production schedule are leading for material flows within the company.

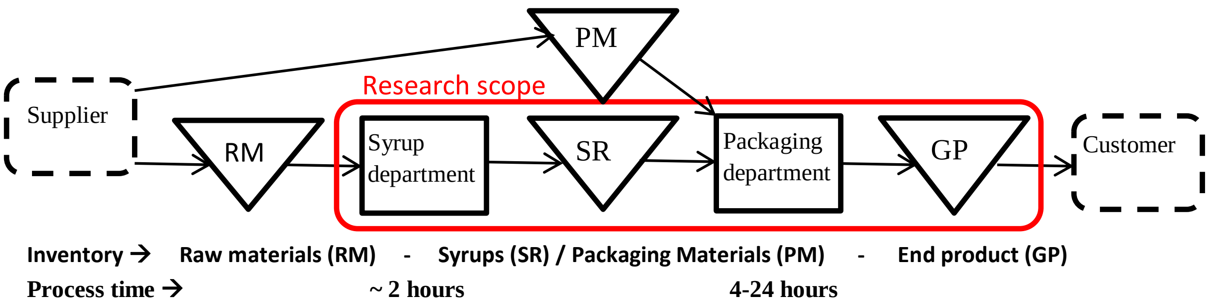


Figure 2: Research scope

The productions of syrups result in Work In Progress (WIP) inventory, because the Syrup department produces syrups before the bottling process of the soft drinks start. With the inventory cost analysis, described in Section 3.3.2, we show that the Finished Goods Inventory (FGI) contributed for 95% of the total inventory costs in 2012. Therefore, this research focuses on the Finished Good Inventory.

The research focuses on production line 4 that bottles 20cl glass bottles with soft drinks for the Out of Home (OoH) industry, and production line 10 that bottles 1.5 litre cartons with soft drink for the retail industry. The reason for this selection refers to the different production capacity characteristics of the production lines and the demand characteristics for soft drinks of the production lines. Production line 10 has excessive production capacity, because of the low demand for 1.5 litre soft drinks in cartons, in relation to available production capacity. On the other hand, this production line has to deal with high volatile demand, which makes it harder to develop a stable 26 weeks production plan. Production line 4 does not have excessive capacity to bottle the high demand for these soft drinks. Sometimes, the production of production line 4 produces in overtime, during the weekend, to serve the customer demand in the high season. In contrast with production line 10, this production line has a more stable demand pattern. With production line 4 and 10, we can show how the planning approaches construct production plans for different production capacities and demand characteristics.

The nine production lines have their own packing type and production specifications. Chapter 3 briefly discusses the specifications of the production lines with a more extensive discussion of production lines 4 and 10. At the end of the research, we assess the selected planning approach on feasibility for implementation to the other production lines.

1.2.2 Causes and effects of the research problem

Vrumona addresses cost reduction for inventory and production as the main aim to start this research. With the knowledge of the production planning approach, Vrumona expects that both costs can be reduced by a novel production planning approaches with weighted parameter values. The current improvement projects of Vrumona focus either on the optimization of the inventory level or the optimization of the production process. This research assesses both the inventory level and production process, with the central problem “Production and inventory cost higher than expected”.

The first cause of the central problem, the production plan does not fulfil all customer demand, because Vrumona does not know the trade-off between inventory- and production costs, and other necessary information is missing. The second cause, the production planner specifies the production sequence for the production weeks and arbitrarily modifies the production lot-sizes and production weeks of the planned soft drinks to fulfil the demand. The third cause, the demand- and production uncertainties do affect the production- and inventory costs. We use these uncertainties as input data for the planning approaches and do not attempt to improve them. Figure 3 shows the causes of the central problem.

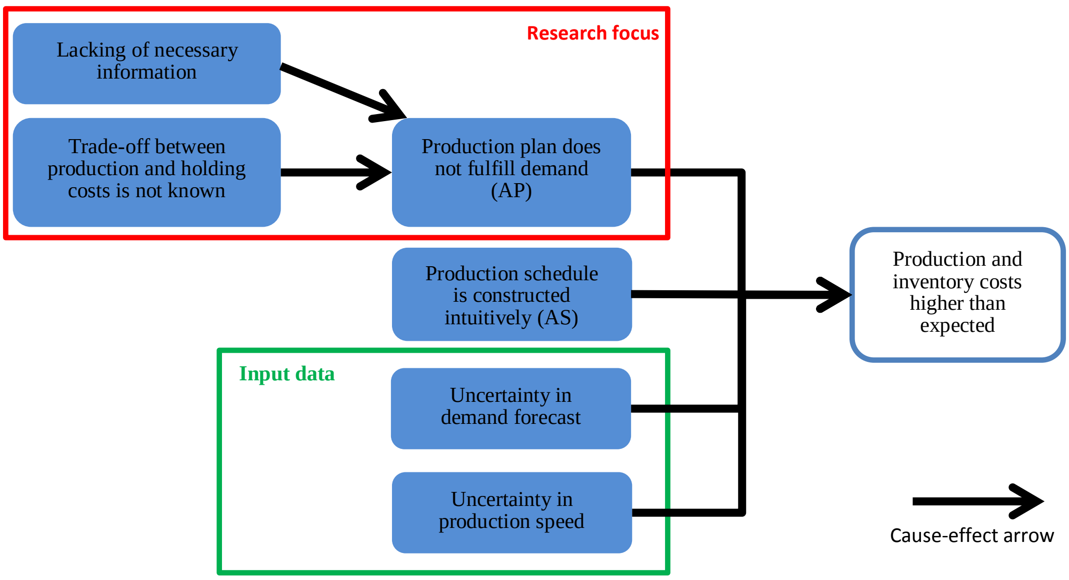


Figure 3: Causes of the central problem, specified to production planning and scheduling processes

1.2.3 Research problem definition

For this research, we define the research problem in dialogue with the employees and the extensive analysis of the Supply Chain Planning department, Production department, and Logistic department. This results in the following research question:

> *How can Vrumona structurally improve their production planning approach to minimize the production- and inventory costs, while maintaining a customer service level of 99.5%?*

To provide an answer to this research question, we define six manageable sub-problems with sub-questions. By structurally answering these sub-questions, we gather important information to answer the research question. We define the following sub-questions:

- **Q1** What literature is available to define improvements for the current planning approach?
  - **Q1.1** How to distinguish the planning processes?
  - **Q1.2** How to define the costs related to the production plan?
  - **Q1.3** What planning approaches are available in the literature?
- **Q2** What is the current situation of the planning processes for the soft drink production?
  - **Q2.1** What are the planning processes of Vrumona?
  - **Q2.2** What are the Key Performance Indicators (KPIs) of these planning processes?
  - **Q2.3** How does Vrumona perform on these KPIs?
- **Q3** What parameters and variables are used by the current planning AP software?
  - **Q3.1** How are these parameters and variables specified?
  - **Q3.2** What are the hard and soft constraints for the production planning and scheduling?
- **Q4** Which costs are influenced by the production plan?
  - **Q4.1** What costs are related to the production costs and inventory costs?
  - **Q4.2** How does the production plan influence these costs?
- **Q5** Which of the planning approaches in literature suit best to the production planning process of Vrumona?
- **Q6** How do these planning approaches perform on the tactical production planning problem?
  - **Q6.1** How to compare these production planning approaches?
  - **Q6.2** How do these planning approaches affect the organization?
  - **Q6.3** What is the best planning approach for Vrumona?
- **Q7** What is the best way to implement this planning approach at Vrumona?
  - **Q7.1** What changes should be made to the production planning process?

1.2.4 Variables and indicators

The main goal of this research is to lower the sum of production costs plus inventory costs by structurally improving the production planning approach, while maintaining or improving the current customer service level. To analyse the current situation of the production planning approach, we define the most important variables which are related to the main research problem: production plan, production costs, and inventory costs. Therefore, this research analyses the following three correlations between these variables to show how the costs can be influenced by the production plan:

- Correlation between production plan and production costs.
- Correlation between production plan and inventory costs.
- Correlation between production costs and inventory costs.

The cost structure behind these costs contains several correlations, however the research focuses on the main correlations to define the costs that can be influenced by the production planning approach. The cost analysis in Section 3.3 defines the production- and inventory costs.

1.3 Research layout

This section provides the research layout of this research. Every chapter provides information to give an answer to one or more sub-questions. Table 1 shows the general structure of the research in tabular format, which shows the content of the chapters and the used research method. This chapter provides the problem formulation and research delineation. Chapter 2 describes the used literature that supports the research problem formulation, to distinguish planning processes, to define production- and inventory costs, and to assess available production planning methodologies for tactical production planning problems. Chapter 3 provides a general description of production departments, describes the current situation of the Supply Chain Planning department, and defines the cost categories related to production- and inventory costs. Chapter 4 formulates alternatives for optimizing the production planning approach. Chapter 5 assesses the production planning approaches on quantitative and qualitative performance measures, to show advantages and disadvantages of these planning approaches. At the end of Chapter 5, we conclude which planning approach fits best to the soft drink production process. Chapter 6 draws the conclusions and provides the recommendations of this research, and also formulates subjects for further research.

Table 1: Research outline

	Chapter	Research method	Research objective
Problem analysis	Chapter 1	Interviews & literature	Problem definition
	Chapter 2	Literature study	Hierarchies of planning (Q1) Cost mapping techniques (Q1) Planning methodologies (Q1)
	Chapter 3	Interviews & data mining	Current situation (Q2 & Q3) Cost analysis (Q4)
Solution design	Chapter 4	Model development	Define planning approaches (Q5)
	Chapter 5	Data analysis	Experimental structure (Q6) Planning approaches assessment (Q6)
Conclusion	Chapter 6		Conclusions and recommendations (Q7)

2 Literature

This chapter provides an extensive and structural literature review to retrieve important information for the research. Section 2.1 answers the research sub-question “How to distinguish the planning processes?” by defining the hierarchical planning levels. Section 2.2 answers the sub-question “How to define the costs related to the production plan?” by describing structural cost analysing methodologies. With these cost analysing methodologies, we define the important cost parameters for the production planning approaches in Chapter 3. Section 2.3 answers the sub-question “What planning approaches are available in the literature?” by assessing several production planning methodologies.

2.1 Hierarchical planning categories

To define the research area, we use the hierarchical planning categories proposed by Anthony (1965). The three proposed hierarchical planning categories that can be distinguished are: strategic planning, tactical planning, and operational control. Zijm (2000) developed a positioning framework, see Figure 4, with on the vertical axis the hierarchical planning categories and on the horizontal axis three managerial categories of planning tasks: technological planning, resource capacity planning, and material coordination (Zijm, 2000).

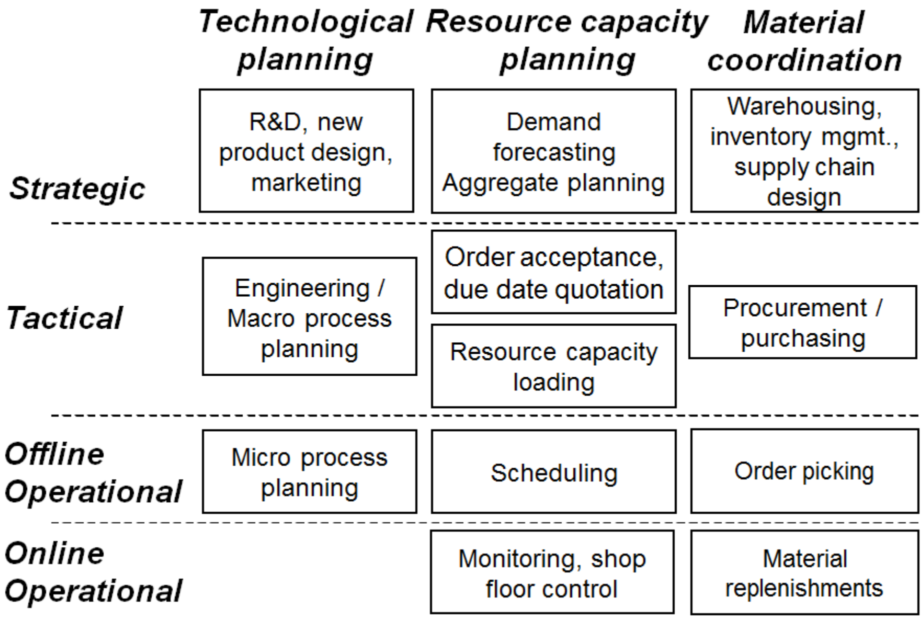


Figure 4: Positioning framework (Zijm, 2000)

For this research, we restrict ourselves to the resource capacity planning column that focuses on the production planning processes. This section provides a detailed description of the three hierarchical planning categories for the production planning processes. The decisions on the strategic hierarchical planning level set the boundaries for the subsequent hierarchical planning levels. For this planning level the uncertainty of available information for planning decisions is more important than the uncertainty of the available information for the medium and short-term planning decisions (Hans, 2001).

First of all, the strategic production planning activities defined as the “Aggregate capacity planning” provides understanding of the effect of strategic level decisions on the tactical and operational level planning activities. The production planning activities on the strategic planning level involve long-range decisions made by senior management. These planning decisions shape the environment of the production planning by make-or-buy decisions, decisions for the location of facilities and decisions about production capacity (Hans, 2001).

Second, the production planning activities on the medium-term tactical planning level involve the middle and top management, and concern the effective use of the available resources (Silver et al., 1998). These planning decisions work within the predefined borders of the aggregated capacity planning and concern the production of sufficient products as efficient and profitable as possible to fulfil the demand. Although the production capacity is defined on the strategic level, on the tactical level it can be adjusted between certain limits. The basic problem that has to be solved on the tactical production planning level is the allocation of the available workforce, machines, storage capacity, and logistic resources to a product type (Hans, 2001).

The operational planning activities relate to short term decisions to define a production schedule with the use of planned production lot-sizes, passed on by the tactical planning module. Baker (1974) defines scheduling as the sequencing and allocation of products to machines over time to perform a collection of tasks. Usually schedules are based on deterministic data and a production planner uses simple dispatching rules to schedule the production batches within fixed time bucket (Hans, 2001).

The research addresses the decisions on the long-term horizon related to production planning, such as decisions on available machine capacity and workforce planning, when these decisions restrict the production plan. The same holds for decisions on the online operational level. Online operational decisions consider changes to the production schedule made to anticipate on the demand fluctuations and production uncertainties (Hans, 2001). Whereas, the scheduling decisions on the offline operational level consider the production constraints for the production sequence and production quantity (Gunther, 2008). In spite that the strategic level and online operational level decisions do not directly relate to our research scope, these decisions constrain the production planning. The impact of the changes to these planning levels has to be analysed carefully, before using them for optimizing the production plan.

2.2 Production and inventory cost literature

This section describes the cost related to production processes and inventory storage by using the principle of Production Value Stream (PVS), which intends to analyse the production performance on cost, effects, and resources (Sobczyk & Koch, 2008).The conceptual framework of PVS measures the performance of a manufacturing process on costs, effects, and resources with the Value Stream Mapping philosophy. Value Stream Mapping (VSM) is a lean manufacturing technique developed by Toyota to analyse and design the flow of the information and materials required on a system level to deliver products to the customers (Rother & Shook, 2003). To measure the system performance, they define four integrated VSM modules, as shown in Figure 5. The module indicated with the number 1 defines the process layout of the analysed departments. With financial information the module indicated with number 2 allocates costs to processes. The module indicated with the number 3 analyses aspects, such as utilization and throughput, of the production processes. Finally, the module indicated with the number 4 adds cost information, used by the company to support their processes.

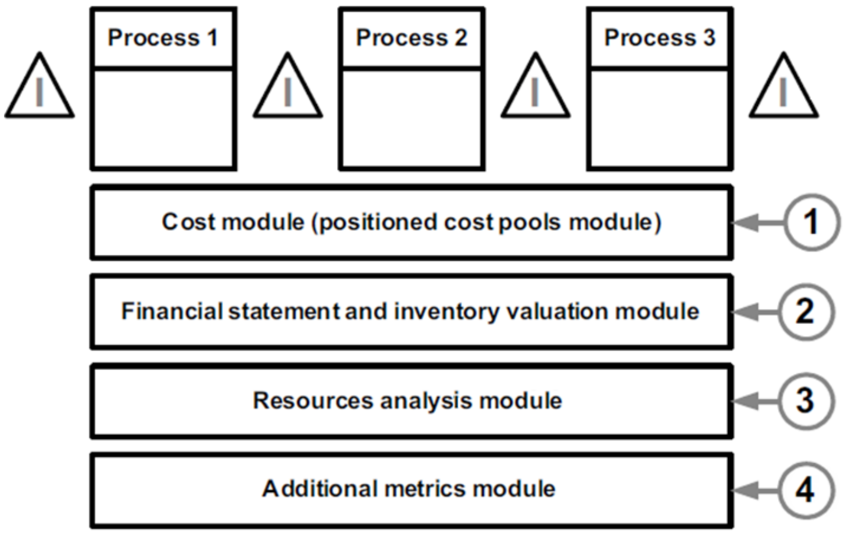


Figure 5: Building blocks of the value stream cost map (Sobczyk & Koch, 2008, p. 153)

With a process flowchart, VSM visualizes the production processes and inventory processes within the company. These process boxes form the basic cost objects for analysis. By breaking down the cost categories of the financial statement into cost pools, the costs can be allocated to the related cost objects. Not all cost categories can be broken down into cost pools that cover a single cost object, therefore these cost pools cover two or more cost objects (Sobczyk & Koch, 2008).

Companies distinguish fixed and variable costs, but the interpretation of these definitions differ per industry. For the production industry, fixed costs are defined as costs independent to the output of the company. These costs remain constant throughout the production process between certain limits of output increase or decrease, while variable costs linearly increase with a production output increase and linearly decrease with a production output decrease (Drury, 2007).

Beside the fixed and variable costs, direct- and indirect costs can be distinguished. The indirect costs cannot be assigned directly to a process, while direct cost can be assigned directly to a process. Improvements to processes affect both the direct- and the indirect costs. Several methods are available in literature to allocate indirect costs to a process. Kirche & Srivastava (2005) propose to use the Activity Based Costing (ABC) philosophy together with the Theory of Constraint (TOC) philosophy to define the inventory- and order costs. The ABC philosophy focuses on indirect cost related to a process or product, and mainly concentrates on the long-term profitability (Schneeweiss, 1998). Combining this philosophy with the short-term accounting philosophy of TOC, the impact of indirect costs on process improvements can be assessed (Kirche & Srivastava, 2005). TOC philosophy focuses on causes of production speed losses per production process. Thereby, it uses the Return-Of-Investment (ROI) to measure the performance of the system and identifies process improvement opportunities (Muthiah & Haung, 2006). The combined ABC-TOC method can be used for planning optimization to make a cost trade-off. This combination opens the possibility to apply more sophisticated planning procedures to tactical optimization problems within production and operations management (Bokor, 2012).

2.3 Production planning literature

This section assesses available production planning methodologies. With the background information of the available planning methodologies, we are able to define alternative to give an answer to our research problem. Section 2.3.1 assesses literature about production planning. The other sections describe the used methodologies for our research more extensively. Section 2.3.2 provides a description of Mixed Integer Linear Programming (MILP). Section 2.3.3 describes the Simulated Annealing technique and Section 2.3.4 describes the Adaptive Search technique. Section 2.3.5 assesses techniques to incorporate uncertainties within the planning model and Section 2.3.6 provides a conclusion on the assessed planning methodologies.

2.3.1 Production planning methodologies

Feylizadeh and Bagherpour (2011) describe the production department as the beating heart of a production company, where the production planning is the most important activity of such a department. Vrumona established a Supply Chain Planning department, which manages the production process, where the production planning plays a central role. To achieve an optimum for the planning processes of the planning department, Maravelias and Sung (2009) conclude that the interconnectivity between the organisation levels within the supply chain should be assessed.

Our research problem can be defined as a Capacitated Lot-Sizing Problem (CLSP), because most of the production lines have to deal with limited available production capacity and the logistic department has to deal limited available inventory capacity. Literature databases contain thousands of approaches for the Capacitated Lot-Sizing Problem (CLSP). These approaches attempt to optimize the production plan. Most of these articles about CLSP provide new insights of monolithic approaches for production planning problems by optimizing an isolated planning level function. These approaches attempt to squeeze production lot-sizes into a production week, without accounting for the impact of the sequence dependent changeover times (Xue, et al., 2011).

The monolithic planning approaches especially account for the tactical planning level of detail and neglect the scheduling level of detail within the model formulation, such as the sequence dependent changeover times. Gunther (2008) concludes that the scheduling level of detail is important for companies in the food industry. A planning method that incorporates this level of detail is the integrated solutions strategy, which integrates production planning with production scheduling (Bokor, 2012). Therefore, we delve deeper into available literature about integrated solutions strategies for production planning to overcome this problem.

Several researches assess integrated solutions strategies, also known as Integrated Production Planning and Scheduling (IPPS) approaches (Grossman et al., 2001) (Maravelais & Sung, 2009) (Xue et al., 2011) (Sung & Maravelias, 2007). Grossmann et al. (2001) conclude that these planning approaches incorporate a more detailed formulation of the production scheduling constraints within the production planning formulation. The solution strategies for IPPS problems, see Figure 6, can be classified into three categories: hierarchical methods, iterative methods, and full-space methods (Maravelais & Sung, 2009).

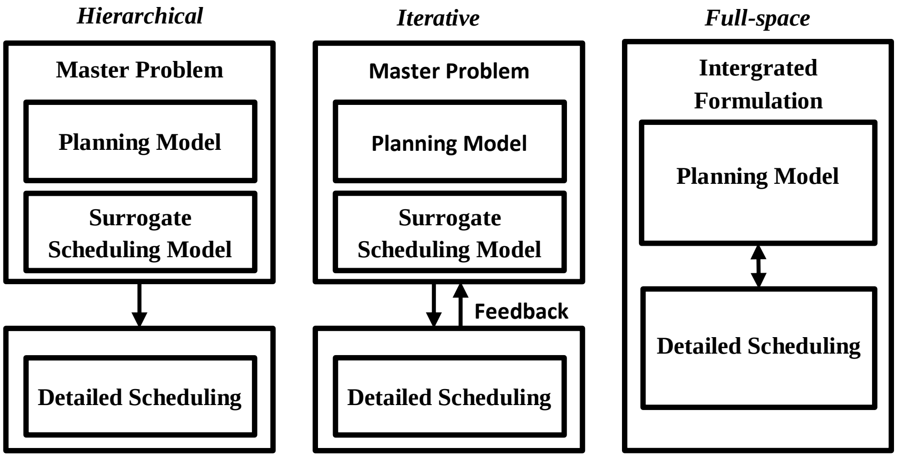


Figure 6: Solution strategies for integrated production planning and scheduling (Maravelais & Sung, 2009).

The full-space method completely integrates the production planning with the detailed production scheduling into one model. Pinedo (2009) and Günther (2008) describe detailed scheduling as a decision making process that concerns the production sequence and the product allocation to capacitated resources by optimizing one or more objectives, whereas surrogate scheduling models concern aggregated formulations of detailed scheduling models to generate feasible planning solutions (Maravelais & Sung, 2009).

The hierarchical and iterative solution strategies integrate the surrogate scheduling model to optimize the master problem and use a detailed scheduling model to generate an optimal production schedule. These solution strategies differ in the solving structure for the IPPS problems, where the hierarchical model consecutively solves the planning and scheduling problem. The iterative model feeds back the scheduling information of the first iteration and solves the whole problem again. The goal of this feedback loop is to generate a more stable and accurate production plan (Maravelais & Sung, 2009).

Integrated Production Planning and Scheduling models combine the monolithic production planning and production scheduling algorithms to find an optimal feasible solution. The full-space IPPS algorithms for complex problems with several constraints, become extremely large and hard to solve (Florian et al., 1980) (Tijm, 2004). Therefore, meta-heuristics became more and more important over the past decades to solve these complex models within polynomial time (Jans & Degreave, 2007). Solution strategies use methods as decomposition, relaxation or aggregation to solve these complex models within polynomial time (Maravelais & Sung, 2009). These methods simplify the mathematical model so it can be solved within an acceptable time period.

Jans and Degraeve (2006) discuss various heuristics to obtain good quality solutions for solving Dynamic Lot-Sizing Problems (DLSP), which takes into account that demand varies over time. They use heuristics such as Tabu Search, Adaptive Search, and Simulated Annealing. The development of meta-heuristics based on combinations of heuristics lead to promising results, where every lot-sizing problem needs its own combination of heuristics to obtain a good quality solution (Jans & Degraeve, 2006).

Ganesh and Punniyamoorthy (2005) propose the Adaptive Search (AS) heuristic, Simulated Annealing (SA) heuristic, and a combination of these two heuristics to optimize a continuous time production planning problem. They test these three heuristics and conclude that the AS heuristic outperforms the SA heuristic on solutions in the global sense, whereas the power of SA lays in improving the local solution. To utilize the strengths of both heuristics, they developed a Hybrid approach. This Hybrid approach first solves the AS algorithm to find a powerful solution and second solves the SA algorithm to improve this solution. Out of the test results, the Hybrid approach outperforms the other approaches on the test problems (Ganesh & Punniyamoorthy, 2005). For the production scheduling problem, a SA optimization approach outperforms the other approaches (Li & McMahon, 2007). This indicates that for the off-line operational scheduling problem or a surrogate scheduling model, the SA heuristic constructs the best solution.

Wan et al. (2005) develop a simulation-based optimization framework with a surrogate models. This simulation-based optimization framework iteratively performs several simulations to construct surrogate models. The simulations define causal relations between key decisions variables and supply chain performance (Wan et al., 2005). With the simulation they analyse the impact of uncertainties to the production plan. Within the simulation-based optimization framework, they embed several optimization and analysing techniques to optimize the solution.

Wellons and Relklaitis (1991) develop a product family scheduling model that accounts for loss of production time, due to the product family changeover times. Product families contain products with equal changeover times for product changeovers within the product family. The changeover times between products of different product family are called the product family changeover time. These product family changeover times are larger than the changeover times between products of the same product family. Wellons and Relklaitis (1991) propose a planning approach that minimizes the total changeover time to planning predefined production lot-sizes for factories with constraining planning capacity. Rajaram and Karmarkar (2004) propose an aggregated planning and scheduling approach that optimizes production lot-sizes and production sequence over the weeks. This approach also uses product families to minimize the total changeover time.

Silver et al. (1998) propose a can-order level, higher than the reorder-level, to assign products of the same product family to a production week with a inventory level higher than the reorder level. The reorder-level specifies when products should be produced to cover the customer demand fluctuations and demand during the production lead-time. The can-order level allows to planning products of a product family with an inventory level between the reorder-level and can-order level to minimize the total changeover time.

Ramezanian et al. (2012) propose stochastic models, such as a Hybrid-Simulated Annealing-neighbourhood algorithm and MILP algorithm, to find an optimal solution for the IPPS problem with limited production capacity. They attempt to find a good quality solution in reasonable computation time for small to large size planning problems and assess the planning approach on total costs. The Hybrid-Simulated Annealing algorithm performs best on either small as large size problems (Ramezanian & Saidi-Mehrabad, 2012). Iris and Yenisey (2011) propose a two-stage heuristic algorithm to solve a Capacitated Lot-Sizing Problem with overtime decisions. Their planning approach iteratively solves two heuristics by making a trade-off between production- , inventory- , and overtime costs. This planning approach first solves a neighbourhood heuristic by using dominance criterion to transform production lots from one period to another and second solves a SA heuristic to find an optimal solution and escape from local optima.

2.3.2 Mixed Integer Linear Programming

The Mixed Integer Linear Programming (MILP) technique is a mathematical technique to find an optimal solution based on linear equations. The basis of this method is the Linear Programming (LP) technique proposed by Kantorovich in 1939 (Chinneck, 2007). This LP technique attempts to optimize a problem with a minimization or maximization objective function, subject to linear equalities and linear inequalities that define the feasible solution space. In contrast to the LP technique, the MILP technique uses integer variables and continuous variables, whereas the LP technique only uses continuous variables. To optimize planning and scheduling problem, the scheduling approach specifies with binary variables whether or not to plan a product in a week. The integer variables make the problem hard to solve within acceptable computation time (Florian et al., 1980).

2.3.3 Simulated Annealing

Simulated Annealing (SA) is based on the idea of Metropolis et al. (1953), who analyse the interaction between molecules when temperature changes. This was the starting point of Kirkpatrick et al. (1983) to develop the SA algorithm, which can be applied to various optimization problems. This section describes the general idea behind the SA algorithm.

The SA algorithm modifies an initial feasible solution (current solution) with small modifications to the variable values, in order to find solutions with a lower objective value. With shift rules, the SA algorithm modifies the current solution. This modified solution is called a neighbourhood solution. When the SA algorithm accepts the neighbourhood solution, it becomes the current solution. The SA algorithm accepts a neighbourhood solution, when this solution has better or equal objective value in comparison with the objective of the current solution, or the SA algorithm accepts a neighbourhood solution with a higher objective value than the current solution with an acceptance probability. The acceptance probability decreases, while the algorithm decreases the acceptance temperature. The acceptance probability makes it possible to escape from local optima by accepting lower quality solutions (Rutenbar, 1989).

The SA algorithm starts with an acceptance temperature τ_{start}. For an acceptance temperature, the algorithm performs a predefined number of modifications, specified by parameter β. After completing these modifications, the acceptance temperature is multiplied by a decreasing factor α to decrease the acceptance temperature. When the acceptance temperature reaches the predetermined termination temperature τ_{stop}, the algorithm terminates. (Ramezanian & Saidi-Mehrabad, 2012).

Depending on the initialization of the parameters: τ_{start}., τ_{stop}, β, α , this algorithm needs an acceptable computation time to find a good quality solution. In addition, it is proven that this algorithm can find a global optimum for complex problems, but this requires infinite computation time (Rutenbar, 1989).

2.3.4 Adaptive Search

The Adaptive Search(AS) algorithm, proposed by Kolisch and Drelx (1996), attempts solving 'hard project scheduling problems'. This algorithm not only has proven its strengths for these kinds of problems, but also for other scheduling and planning problems, such as the hard to solve Travel Salesman Problem.

The AS algorithm combines a random construction technique with a dispatching rule based on priorities to construct a generic solution. In case of a planning problem, for example the chosen dispatching rule “Earliest Due Date First” provides a priority φ_i for a job. The algorithm does not use the priority to select a job, but uses it to calculate the probability P_i of a jobs. This probability gives the likelihood to schedule a job. The AS algorithm uses the regret-factor R_i to calculate the probability of a job. The regret factor is the absolute difference between the worst of all priority and the priority of a job φ_i. When a high φ_i implies a higher priority, the worst of all priority is equal to $min(\varphi_i)$. When a low φ_i implies a higher priority, the worst of all priority is equal to $max(\varphi_i)$. With a higher regret-factor, the more regret you have not to schedule the job. Function 2.1 calculates the probability of a job.

$$P_i = \frac{(R_i + 1)^\alpha}{\sum_{i=1}^{N}(R_i + 1)^\alpha} \qquad (2.1)$$

With the bias parameter α, the algorithm uses a deterministic or random selection procedure. When α = ∞, the algorithm uses the deterministic selection procedure to construct a solution. By decreasing α, the algorithm uses a more random construction technique to construct a solution.

2.3.5 Incorporate uncertainties

Many deterministic mathematical models available in literature work with fixed data to find near optimal solutions for tactical planning problems. Within the manufacturing industry, demand and production have various kinds of uncertainties. These uncertainties are difficult to estimate upfront. In the food service industry, these uncertainties negatively affect the stability of the production plan and schedule (Gunther, 2008) (Rajaram & Karmarkar, 2004). Various researches attempt to incorporate these uncertainties within the planning model to optimize the production planning or production schedule (Ramezanian & Saidi-Mehrabad, 2012) (Helber et al., 2013) (Darwish et al., 2012). As already discussed, Wan et al. (2005) uses a simulated-based optimization approach with surrogate models to incorporate these uncertainties, to optimize the production planning problem.

2.3.6 Conclusion

Monolithic planning approaches use average changeover times to approximate the production capacity utilization of a week. With these average changeover times, these planning approaches are unable to minimize the total changeover time for a manufacturing process with sequence dependent changeover times. To incorporate planning level decisions, we use the Integrated Production Planning and Scheduling (IPPS) approaches bases on the hierarchical solution strategy. This solution approach attempts to incorporate the decisions made on the offline operations planning level in the tactical planning level. Moreover, this solution approach solves two separate problems in an consecutive manner and does not define a full-space model that results in a complex model, which is hard to solve.

We formulate IPPS approaches by using the MILP algorithm and the Adaptive Search algorithm together with the Simulated Annealing algorithm to solve the tactical planning problem. Both approaches can solve complex production planning problems. To incorporate the production schedule problem within the planning approaches, we use product family changeover times and costs. In addition, we use a Simulated Annealing algorithm to solely improve the production sequence in a week. Chapter 4 explains why we choose for these approaches and explains how we use these algorithms to construct a production plan.

3 Current situation

This chapter describes the current situation of the Syrup department, Packaging department, Logistic department, and Supply Chain Planning (SCP) department at Vrumona. The production of soft drinks starts with the production of syrups, which are transported to the Packaging department. The Packaging department adds water to the syrup and bottles the soft drinks. Section 3.1 describes the Syrup department, Packaging departments and the Logistic department. Section 3.2 provides a detailed description of the production planning processes of the SCP department and Section 3.3 assesses the correlation between production costs, inventory costs, and production plan.

3.1 Production departments

This section describes the Syrup department, Packaging department, and Logistic department. Furthermore, this section describes the relevant constraints of these departments for the production planning and production scheduling processes.

3.1.1 Syrup production

The Syrup department produces syrups and is responsible for the cleaning of the syrup distribution pipelines to the production lines and the cleaning of the syrup storage tanks. Two parallel compound dissolvers and two parallel batch mixers combine and mix the ingredients for the syrups. This process takes between two to four hours, depending on the type and the production quantity of the syrup. After the syrup production, the syrup operators store the syrup in one of the fourteen storage tanks. The syrups can be stored between 12 to 72 hours, depending on the shelf life of the syrups. Figure 7 show the layout of the Syrup department.

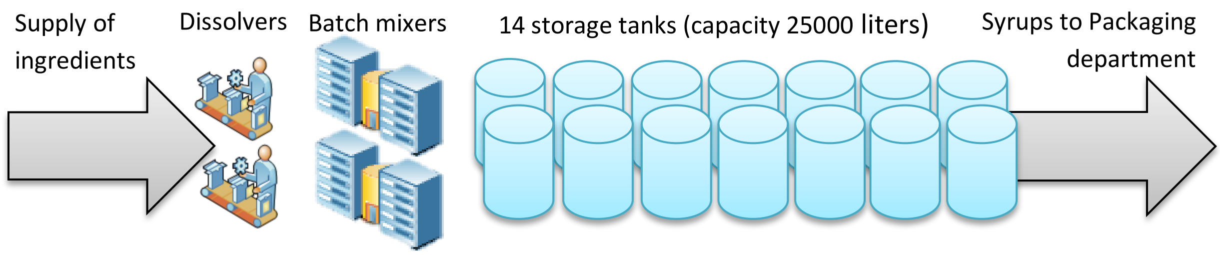


Figure 7: Layout Syrup department.

The Syrup department uses the daily packaging production schedule (BAS) to schedule the syrup productions. The syrups need to be produced in advance to have them available before the Packaging department starts the soft drink productions.

The syrup department contains equipment to produce large syrup volumes. The batch mixers have to produce batches of at least 5000 litres of syrup to guarantee the syrup quality. The minimum production lot-size constraint secures the syrup quality. In addition, each storage tank has a storage capacity of 25000 litres of syrup. A larger syrup lot-size than the storage tank capacity occupies more than one storage tank.

The number of soft drinks that can be bottled with the minimum syrup production quantity depends on the syrup water ratio. Production lot-sizes above the minimum production lot-sizes are constrained by packaging sizes of the ingredients. This results in a multiple batch size constraint that defines the production lot-size increase above the minimum production lot-size.

3.1.2 Packaging department

The Packaging department adds water to the syrups and bottles soft drinks. For the production process, the Packaging department has 9 production lines available for different soft drink package types. A normal working week for the packaging production process starts at 7.00 AM on Monday and ends at 7.00 PM on Friday. To fulfil the demand, production lines need to operate 24 hours a day. Therefore, Vrumona works with three 8-hour production shifts to have workforce 24 hours per day available. Vrumona stipulates the workforce planning one year in advance for the Packaging department. The management can decide to use extra production capacity against extra costs, when the demand cannot be fulfilled with the available production capacity.

The production losses of the Packaging department, see Table 2, show that the effective production times for production lines 4 and 10 are respectively 61.1% and 72.1%. This table shows that 19% of the machine losses for production line 4 and 15.3% of the machine losses for production line 10 contribute to the production uncertainties: breakdown and speed losses. The production plan and production schedule affect machine losses for changeover-time and planned downtime. This research assesses both machines losses.

Table 2: Performance of the production lines 4 & 10 (over the year 2012)

Production losses (2012)

Machine losses

Type of loss	Production time	Changeover time		Planned downtime		Breakdown	Speed losses	Sum
	% actual	% Actual	% Target	% Actual	% Target	% Actual	% Actual	% Target
Production line 4	61.1	14.8	12.0	5.1	6.6	11.7	7.3	18.0
Production line 10	72.1	7.5	9.0	5.1	4.9	9.7	5.6	18,0

Production speed

Production speed (collo/hour)		Theoretical	Planned
Production line 4	Pasteurizer	1857	1281
	Non pasteur	2143	1436
	Tomato juice	1500	1005
Production line 10	1.5 ltr cartons	687	515

Material losses

Packaging material (of total expense)	Norm %	Actual %
Glass bottles	0.99	2.52
Cartons (Tetra)	1.27	6.5
Syrup (of total expense)	**Norm %**	**Actual %**
Syrup losses total	2.22	2.4

Employees losses (Operational employees)

Overtime work (150%/200%/300%)	Time (hours)
Cluster colonne 4/5	1600
Cluster colonne 3/6/7/9/10	700

Overtime work (150%/200%/300%)	Time (hours)
Syrup department	300
Logisitic department	2300

Table 2 also shows the theoretical and planned production speed, material losses, and overtime work hours for production lines 4 and 10 in 2012. The production speed of a production line depends on the packaging type, but the production speed of production line 4 depends on the soft drinks that use the pasteurization process or not. The production line 10 bottles only soft drinks with the same packaging type, so this production line produces soft drinks with the same production speed. In addition, the material loss for carton packages is 5 times higher than the target and the material loss for glass bottles is 2.5 times higher than the target.

3.1.3 Logistic department

The Logistic department handles the produced soft drinks and has two onsite storage locations available to store soft drinks. In order to meet the customer service level target of 99.5%, all soft drinks are produced to stock. This department also operates 24 hours a day, until the all produced soft drink are shelved. The available operational workforce for the Logistic department differs for the morning, afternoon, and night shift. Appendix C provides an overview of the available operational logistic workforce.

The largest storage location “Hal West” shelves soft drinks of production lines 1 till 6 and has a store capacity of 18500 pallets. The other storage location “Oude Hal” shelves soft drinks of production lines 7, 9, and 10 and has a storage capacity of 1900 pallets. When the number of produced soft drinks exceeds the internal storage capacity, the logistic department transports soft drinks to an external storage location with higher storage costs.

When Vrumona cannot deliver demand, out-of-stocks occur. These out-of-stocks can have several reasons. For this research, we focus on the out-of-stocks which occur due to the production planning and scheduling processes. These out-of-stocks result in excessive waiting time of a truck or unfulfilled customer orders.

3.2 Supply Chain Planning department

This section describes the production planning processes of the Supply Chain Planning department. The planning cycle starts with demand forecasting, followed by production planning, production scheduling, and material planning. These production planning processes use software tools that support the decision making process. The Enterprise Resource System (ERP) software provides information to and receives information from the software tools.

Figure 9 graphically shows the production planning process of the Supply Chain Planning department, where the arrows represent the information flow. The first column indicates which days of the week the planning process is performed. The second column shows the ERP software package (SAP) of Vrumona together with the modules used by the Supply Chain Planning department. The third column shows the four planning processes, with the used software tools between brackets. The fourth column shows the daily production schedule, which is delivered to the production department.

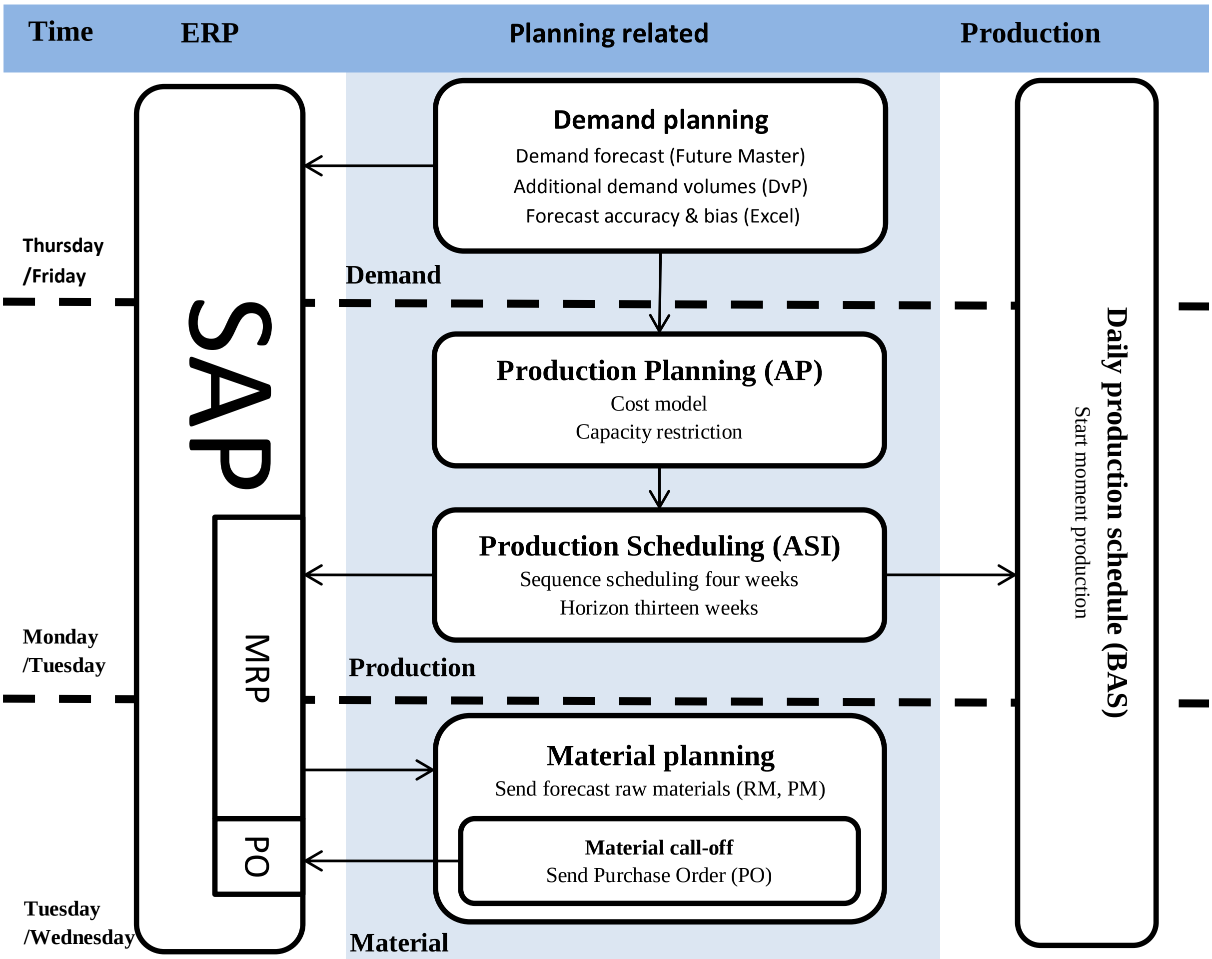


Figure 9: Production planning processes Vrumona

3.2.1 Demand planning

The demand planning process provides the demand forecast. The demand forecasts consist of baseline demand, additional demand for promotions, demand of newly introduced soft drinks, and demand loss of soft drink remediation. The demand planner uses the software tool Future Master (FM) that analyses historical demand, excluding additional demand volumes, to provide the baseline demand per soft drink. This baseline demand is combined with the other forecasted demand volumes in Future Master.

It is important to assess the reliability of the demand forecast, because Vrumona strives to meet a customer satisfaction service level of 99.5% to fulfil the customer demand. When the demand forecast provides an unreliable representation of the sales, it affects the customer service level of the production plan.

Vrumona uses Heineken standards to measure the customer satisfaction service level. Heineken states four customer satisfaction service level measures, see Table 3, with the formulations and the accomplished customer service levels in 2012.

Table 3: Customer satisfaction service level (Heineken, 2011)

Customer satisfaction service-level		
Measure	**Formula**	**2012**
On Time	$\frac{\#\, orders\, deliverd\, within\, the\, agreed\, time\, window}{Total\, orders\, delivered}$ *100%	93.6%
In Full	$\frac{\#\, orders\, deliverd\, in\, the\, right\, quantity}{Total\, orders\, delivered}$ *100%	98.8%
Product Availibility	$\frac{\#\, confirmed\, orders\, by\, the\, customers}{Total\, orders\, delivered}$ *100%	99.3%
Perfect customer order	On Time * In Full * Product Availibility * 100%	91.8%

Vrumona measures the reliability of the demand forecast with forecast accuracy and forecast bias measure provided by Heineken. The demand forecast accuracy differs per production line, with an average forecast accuracy around 80%. Table 4 shows the actual demand forecast accuracy per production line over 2012 together with forecast accuracy targets and forecast bias. The forecast accuracy percentages are calculated with Function 3.1. Note that this forecast accuracy measure can results in negative values. Therefore, literature does not use this forecast accuracy measure. We use this forecast accuracy definition, because the forecast accuracy targets relate to this definition.

$$Forecast\ accuracy\ = 1 - \frac{Absolute(Forecasted\ demand - Actual\ demand)}{Forecasted\ demand} \tag{3.1}$$

The forecast accuracy measure uses the absolute difference between forecasted demand and actual demand in a week and does not take into account structurally underestimation or overestimation of actual sales. The forecast bias provides this information. The forecast bias per production line is computed with Function 3.2 that uses the definition of Silver et al. (1998). We do not use the Heineken standard, because this does not arbitrarily show underestimation or overestimation of the demand forecast.

$$Forecast\ bias\ = \frac{(Forecasted\ demand - Actual\ demand)}{Actual\ demand} \tag{3.2}$$

Every year the management states new demand forecast accuracy targets. With Process Kaizen Engineering (PKE) project teams, Vrumona attempts to improve forecast accuracy to meet these targets. Table 4 shows the percentage demand volumes of production line and the performance of the demand forecast over 2012. The demand forecast accuracies for production lines 9 and 10 were higher than the targets, due to fact that both production lines produce a small number of soft drinks with less promotion volumes. In addition, these production lines have a lower forecast accuracy target compared to the other production lines.

Table 4: Demand planning (2012)

Demand planning (2012)

Demand volumes

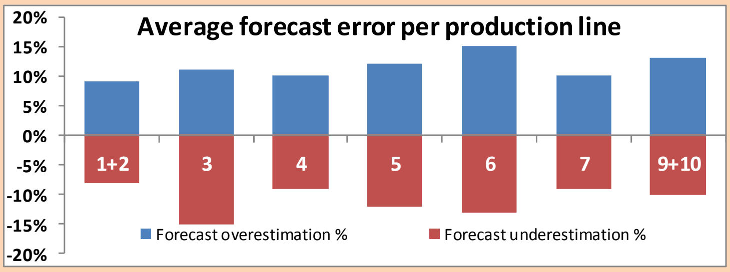
Production lines	% of total
Production line 1+2	60.6%
Production line 3	5.5%
Production line 4	11.5%
Production line 5	2.3%
Production line 6	3.0%
Production line 7	0.8%
Production line 9+10	6.7%

Types of products

Syrup (euro)	#
Number of SKU's	252
• # packaging raw materials	300
Number of syrup types	100
• # syrup raw materials	150

Forecast

Production lines	1+2	3	4	5	6	7	9+10
Actual accuracy (t-1)	79.6%	76.6%	86.7%	83.2%	81.3%	84.5%	79.4%
Target accuracy (t-1)	83%	77%	89%	87%	87%	85%	73%
Forecast bias	-1.0%	-8.0%	-0.2%	-3.0%	-0.3%	-3.0%	0.7%
# Underestimated	29	41	27	33	29	36	27
# Overestimated	23	11	25	19	23	16	25



Soft drinks for the Out of Home (OoH) industry have promotions volumes on a smaller scale than soft drinks for the retail sector. This result in a more accurate demand forecast for production lines 4, 5, 6, and 7, although the forecast accuracy for three of the four production lines performs below the forecast accuracy targets. The reason for this is that the OoH industry experiences a large impact of weather and it contains seasonality trends.

For all production lines except production lines 9 and 10, the forecast structurally underestimates the actual sales. Production lines 3 and 6 have the highest underestimation of the demand with respectively 15% and 13%. Production lines 6, 9, and 10 have the highest overestimation with respectively 15% and 13%.

3.2.2 Production planning and scheduling

The production planning software Advanced Planning (AP) specifies the production lot-sizes and production weeks for the soft drinks, but does not define the production sequence in a week. The production planner updates the input data and freezes the first four weeks of the production plan, because these weeks are scheduled in the previous week. Freezing the first weeks of the production plan is a common used method to reduce the nervousness or instability of the production plan, while it results in higher total costs and a lower customer service level (Zhao & Lee, 1993) (Mehrotra et al., 2011). Figure 10 shows the production planning and production scheduling horizon of Vrumona.

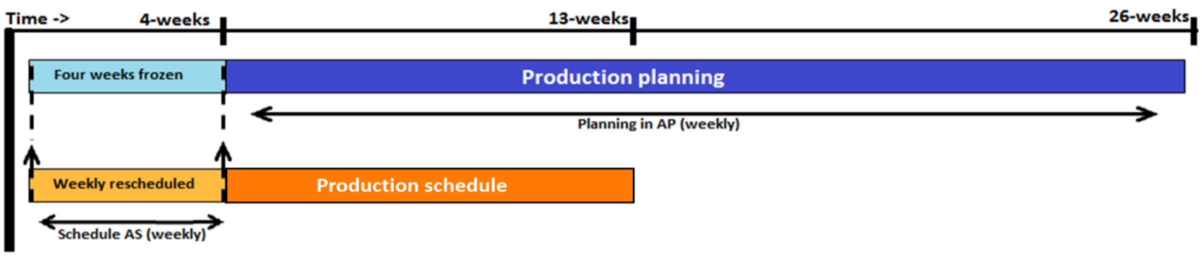


Figure 10: Production planning and production scheduling horizon.

The updated input data, such as demand data, product data, and planning parameters are feedback into AP. With a predefined cyclic week structure called “planning pattern”, the production planner can force AP to periodically plan soft drinks. It can be questioned to which extent a planning patterns impact the total cost of the production plan (Mehrotra et al., 2011). Table 5 shows the planning parameters of the AP algorithm. The production planner arbitrarily defines the planning parameter values. It is doubtful that these arbitrarily defined parameter values lead to the best production plan.

Table 5: AP planning parameters

Parameters AP

Cost priorities	Production lot-sizes	Inventory level
Inventory cost priority	Minimum lot-size	Minimum stock level (days)
Production cost priority	Maximum lot-size	Maximum stock level (days)
Out-of-stock cost priority		Inventory coverage degree (weeks)

Syrup losses
Production pattern (Soft drink have fixed production weeks)
Priorities of SKU’s (Products with a higher priority are produce before product with a lower priority)
Production speed
Service level

The AP software uses an optimization algorithm, whereby the processes of the Production department receive a higher priority than the processes of the Logistic department. This AP model is developed for the strategic global supply chain production planning for Heineken. To use AP model for tactical production planning problem of Vrumona, the software engineer of Heineken aggregated the model to a single production facility model. With this model, AP constructs a linear mathematic optimization formulation to solve the production planning problem. The IBM Ilog Optimizer solves the mathematical formulation that keeps track of the defined planning constraints (Infor, 2013). Vrumona uses cost priorities and priorities for the planning constraints to overrule a constraint when the software cannot construct a feasible production plan within the pre-set boundaries. With cost priorities, the production planner defines a trade-off between inventory- and production costs.

Within the first four weeks of the production plan, the production planner modifies the production lot-sizes and production week of the planned soft drinks to cover the demand fluctuations and avoid soft drink shortages. The production planner shifts productions to an earlier or later production week or modifies the production lot-size, for soft drinks with inventory coverage below one week or above three weeks of demand. The production planner processes modifications to the production plan on the following measures:

- Expected out of stock → produce earlier or increase production lot-size.
- Over stock → postpone production or decrease production lot-size.
- Excessive lot-size → split production into two production lot-sizes.

The production planner weekly modifies the production sequence for the next four weeks. The scheduling software Advanced Scheduling (ASI) graphically shows the changeover times between production changeovers and shows the duration of the production runs. ASI supports the decision making process of the production planner to construct the production schedule. The weeks 5 to 13 of the production schedule show the utilization of the production capacity in the near future, but the production planner does not schedule the planned productions for these weeks.

To make the production schedule, the production planner takes care of exceptions and rules defined for the sequences of the productions. The stringent food-safety standards result in high sequence dependent changeover times for soft drinks. The production planner specifies the production sequence per week, based on a natural production sequence; a sequence that starts with low taste soft drinks and ends with strong taste soft drink. The natural production sequence minimizes the total changeover time, while obeying the soft drink quality standards. The production planner clusters soft drinks to product families to structurally build the production schedule. The soft drinks of a product family share the same changeover time and the changeovers between soft drinks of different product families use a larger amount of changeover time. The production sequence exceptions and the natural production sequence result in a near optimal production schedule.

Every production line bottles soft drink in different packaging types and has different sequence dependent changeover time specifications. Table 6 shows the most important sequence dependent changeover specifications for production lines 4 and 10. Appendix A provides the full specifications and priorities per production line. Production line 4 bottles several soft drinks in 20cl bottles, within two colours of glass bottles. The green colour glass bottles are used to bottle 7Up and tomato juice. The other soft drinks are bottled in white colour glass bottles. On this production line, every soft drink changeover consists of changing the labels, caps of the bottles, supply of soft drink, and sometimes the bottles. Production line 10 produces two soft drink brands with several flavours in 1.5 litre cartons. The soft drink changeover for this production line consists of changing the printed carton roll, caps, and supply of soft drink.

After each production of a soft drink, the production lines have to be cleaned. The duration and type of the cleaning activities depend on the prior produced soft drink on the production line. In addition, some soft drink changeovers are not allowed, due to quality standards. In general, the production planner takes care of the changeover categories and preferences, shown in the column “Product specifications” of Table 6. At the end of a week, comprehensive cleaning of the production lines takes place. This operation also includes the necessary sterilization before shutting down the production lines over the weekend. In addition, it is preferred to start with soft drinks that use the same bottle type, the production line is ended with in the previous week.

Table 6: Sequence dependent changeover time specifications (production lines 4 and 10)

Sequence dependent changeover time specifications

Mechanical changeover

Production line 4 (Glass bottles 20cl)
Pasteurization
White glass
Green Glass

Production lines 10 (Tetra)
Carton role

Changeover preferences

Product catergories for changeovers
Hard products
Soft products
Fruit products
No-bubbels/bubbels

Prefferend products for begin week
Same package type, where the production is ended with.
Sourcy Blauw
Pepsi Regular
No syrup needed
Syrup directly availible

Prefferend products for end week	
Sourcy Blauw	Stop without syrup loss
Pepsi Regular	Stop without syrup loss
Lipton products	Long cleaning time (165 minutes)
Tomato juice	Long cleaning time (345 minutes)
Climax	Long cleaning time (270 minutes)

Soft-drink per production line

Soft-drinks / Production line	1	2	3	4	5	6	7	9	10
Sourcy Blauw		●	●	●	●				
Sourcy Rood		●	●	●	●				
RC Sodawater			●						
Cristel Clear products	●	●	●	●					●
Sisi lemonade	●	●	●	●			●	●	●
Sisi Fruitmenia products								●	●
Royal Club lemonade	●	●	●	●		●	●		
Rivella	●	●	●	●		●	●		
Seven-up products	●	●	●	●		●	●		
Pepsi products	●	●	●	●		●	●		
Lipton	●	●	●	●		●	●		
Climax				●			●		
Jus d'Orange				●	●				
Tomato juice				●					
Apple juice				●	●				
Multifruit njuice				●					

Cleaning changeover

Cleaning activities (CIP)	Time (min)
Cold water CIP	60
Hot water CIP	110-150
Loog CIP	130-190
Dubble- Loog CIP	270
Stikstof Cip	55
End week CIP	240-300
Start week CIP	Normal CIP
End week CIP	240-300

To make a production plan or schedule, the planner should take into account several constraints. Not all of these constraints are used in the AP software. Therefore, the algorithm does not correct the production lot-sizes and production week for all these constraints. The production planner has to cope with the following constraints:

Hard constraints

- Minimum lot-size for production (syrup production)
- Tiered increase of production lot-sizes (ingredient packaging sizes)
- Production capacity of the production lines (available workforce)
- Maximum shelf life of syrups
  - The shelf life of syrups is between the 12 and 72 hours
- Limited sales-term of soft drinks
  - The sales-term of soft drinks is between ¼th and ½th of the “best-before date”
- Product ranges per production line
- Sequence dependent changeover-time
- Maintenance of the machinery (Preventive Maintenance)

Soft constraints

- Combination of work shift to production lines
- Maximum and minimum production lot-sizes
    - Restricted by the syrup department
- Maximum and minimum inventory levels
    - Restricted by the logistic department
- Available storage room at the production side.
    - Extra storage could be retrieved against extra costs.

3.2.3 Material planning

The material planning process subsequently follows-up the production scheduling process. The Enterprise Resource System SAP constructs a Material Requirements Planning (MRP) for the raw materials, whereby it indicates when raw materials should be ordered and in which quantity. The material planning process uses the production schedule to develop the MRP. On Tuesday and Wednesday, the material planner sends purchase orders with the delivery moment and order quantities to suppliers and anticipates on short-term modifications to the production schedule. When modifications affect the delivery moments and/or order quantities, these modifications are communicated with suppliers to have all raw materials on-time available.

Every Thursday the material planner checks the MRP for the upcoming week on availability of raw materials. SAP indicates issues with material availability, when needed the material planner takes action to cover the raw material demand. The material planner takes no action, when the available safety stock is enough to cover the raw material demand for planned productions.

3.2.4 External production planning

Vrumona outsources the production of the Sourcy Vitamin Waters, Gatorade, Royal Club GOOOD Energy and some other soft drink to external vendors. The suppliers transport the raw materials for these soft drinks directly to the external venders. The external production planning process is beyond the scope of our research.

3.3 Production and inventory costs

This section provides the cost analysis, which uses the data from the profit and loss account of the Production department and Logistics department, and defines the susceptible costs for the production planning. Appendix E provides a more extensive cost analysis.

The profit and loss account distinguishes fixed and variable costs categories. Fixed costs that cannot be assigned to a production line are called overhead costs (Jarvis & Berry, 2008). Table 7 shows the major cost categories for the production- and inventory costs, with their contribution to the total production- or total inventory costs over the year 2012. The table shows that the labour expenses contribute most to the production costs, while the labour expenses are the second most important cost driver for the logistic costs. The external transport is the most important cost driver for the logistic costs. In addition, Vrumona defines the labour expenses as a fixed expense, because of the fixed workforce planning for the Production department and Logistic department.

Table 7: Production and logistic costs (2012)

Production and logistic costs (2012)			
Production cost		**Logistic cost**	
Fixed production costs/year		**Fixed inventory cost/year**	
Fixed assets	19.7%	Internal storage assets	9.7%
Labor expenses	40.7%	External storage assets	3.0%
Repair and maintenace	20.6%	Labor expenses	34.9%
Energy and water	12.0%	Repair and maintenace	3.3%
Other fixed expensis	3.8%	Energy and water	0.2%
Variable production costs/year		**Variable inventory cost/year**	
Miscellaneous material	3.1%	External transport	41.4%
Other variable expensis	0.1%	Internal transport	7.5%

The Value Stream Map, see Figure 11, shows the cost categories related to the production planning processes. The production plan and production schedule directly influence the production costs, whereas material planning partly influences the production costs. Costs related to production changeovers, depend on the production planning and production scheduling processes. The material planning process can result in a delay of the production, when the raw materials are not available.

The inventory costs relate to the material planning and production planning, because the delivery date of raw materials affect raw material inventory, whereas the production moment and the production lot-size affect the finished goods inventory. The out-of-stock costs cannot be directly assigned to one planning process, because it has several causes. The upcoming Sections 3.3.1 till 3.3.3 provide the analysis of the cost categories.

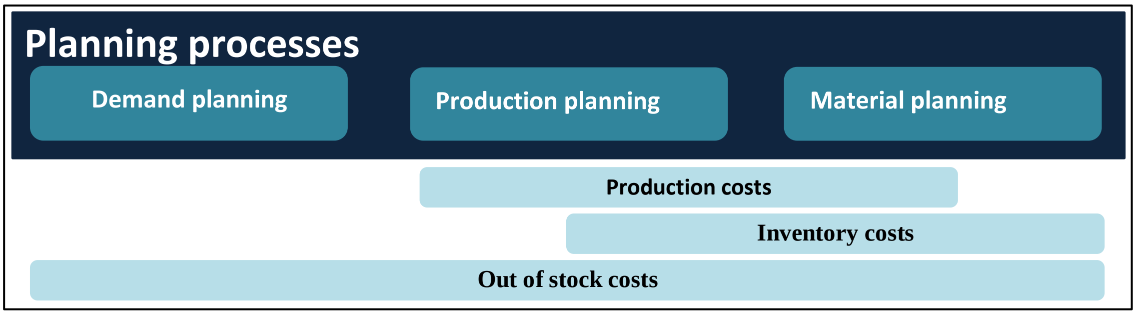


Figure 11: Influence of planning processes on costs

3.3.1 Production costs

The susceptible production costs relates to the production changeovers and overtime productions. We assign the direct costs either to the production changeover or overtime production activities. The production plan does not affect the indirect production costs, such as production equipment and maintenance, so we do not assign these costs to the production costs. Table 8 shows the changeover- and overtime costs, which are defined in dialogue with the Production department. By further investigating the changeover- and overtime costs, the cleaning costs and energy costs do not significantly contribute to the changeover costs, because the Syrup department recycles the cleaning liquids and production lines do not operate during production changeovers.

Table 8: Changeover costs and overtime production costs

Changeover costs	Ovetime production costs
Material losses / changeover	Labor expenses / production hour in overtime
Energy costs / changeover	
Cleaning costs / changeover	
Labor expenses / production hour	

When the production runs in overtime, employees of the Syrup department, Packaging department, and Logistic department have to work until the last pallet of soft drinks is shelved. We define the overtime costs as the labour costs times 150%, plus an additional fee to account for additional costs, such as energy costs.

Modifications to the production planning indirectly affect the order costs related to material call-off process. These order costs strictly relate to the used inventory management strategy, used to make a trade-off between the inventory- and order costs (Silver, et al., 1998). Although these costs can somehow be allocated to the production costs, we do not allocate these costs to the production costs, because the material planning can be optimized separately.

3.3.2 Inventory cost

The inventory cost consists of internal inventory storage costs and external inventory storage costs. Durlinger (2008) concludes that companies define their internal inventory storage costs as a fixed percentage, commonly 25%, of the product transfer price. Most of the companies take this percentage for granted and do not know the background. The available cost literature defines cost allocation methods to map cost drivers for inventory processes, but they do not define inventory costs to make a trade-off between production- and inventory costs. We use the three costs categories presented by Durlinger (2008), to define the inventory costs:

- Interest: Weighted Average Cost of Capital (WACC)
- Space: Costs for storage and handling
    - Fixed inventory storage costs
    - Variable inventory storage costs
- Risk: Cost of risk
    - Variable costs (such as insurance, pilferage, and obsolescence)

Vrumona distinguishes four types of inventories: raw materials syrup (RM), produced syrup (SR), packaging materials (PM), and finished products (GP). The profit and loss account only distinguishes inventory location costs for packaging material (PM) and finished goods inventory (GP). The ratio of inventory location costs for packaging material (PM) and finished goods inventory (GP) is respectively 5% over 95%. Therefore, we focus on the costs for the finished goods inventory.

The cost of capital includes the interest paid over the outstanding inventory capital for the finished goods inventory. Table 10 shows the percentage outstanding capital of the inventory categories for production lines 4 and 10. The finished goods inventories for both production lines contribute more than 50% to the total outstanding inventory capital. By lowering the inventory levels, the outstanding capital decreases simultaneously.

Table 9: Outstanding inventory capital per inventory location

Outstanding inventory capital		
Ratio inventory point	**Line 4**	**Line 10**
Raw materials syrup (RM)	20%	20%
Produced syrup (SR)	1%	1%
Packaging materials (PM)	28%	26%
Finished product (GP)	51%	53%
Total	100%	100%

The fixed inventory storage costs include the storage location costs and material handling equipment costs. The onsite storage locations of Vrumona are free from interest and the material handling equipment costs are not directly affected by an increase or decrease of the total stored inventory. Therefore, we do not include the fixed inventory storage costs to the inventory costs.

The variable inventory storage costs include the labour expenses. The labour expenses can be divided into three storage activities: handling in, handling to restore, and handling out. Every pallet with soft drinks uses once the handling in and handling out activities. These activities do not depend on the inventory level, but the number of handling to restore activities increase, when the inventory level increase. Therefore, we assign the costs for the handling to restore activities to the variable inventory storage costs.

Holding inventory increases the risk for obsolete soft drinks, soft drink pilferage, or soft drink damages. The costs for pilferage or damages are not significant, but the obsolescence costs for the soft drinks of some production lines are significant. Therefore, the risk costs contain the obsolescence costs.

External storage costs for the finished goods inventory contain the third party warehousing costs and transportation costs to transport the soft drinks to the external warehouse, and the transportation costs from the external warehouse to the onsite storage locations. These costs can be reduced when all inventories can be stored onsite.

3.3.3 Out-of-stock cost

The out-of-stocks at Vrumona have several reasons. The costs for the different out-of stock reasons are not measured, because Vrumona steers on zero out-of-stocks. Therefore, the production planner uses a significantly high out-of-stock cost priority to force the AP software to avoiding out-of-stocks. In addition, the production planner modifies the schedule when out-of-stocks occur in the four weeks scheduling period.

3.3.4 Conclusion

The current planning approach uses changeover cost priorities, inventory cost priorities and out-of-stock cost priorities to make a trade-off between inventory and production costs. For our planning approaches we use changeover costs, overtime costs, internal inventory costs, external inventory costs, and backorder costs. The changeover costs contain the labour costs per changeover and the costs for the syrup losses during production changeover.

The overtime production costs contain the labour costs of the Syrup department, Packaging department, and Logistic department, plus an additional fee to penalize overtime production.

The inventory costs are divided into internal inventory costs and external inventory costs. The internal inventory costs contain interest costs, costs for the handling to restore activities, and obsolescence risk costs. The external inventory costs contain third party warehousing costs and transportation costs to and from the external warehouse.

4 Model development

This chapter answers the sub-question "Which of the planning approaches in literature suites best to the production planning process of Vrumona?". In order to answer this question, Chapter 2 qualitatively assesses the relevant literature about production planning optimization, which we use for selecting suitable planning approaches. Section 4.1 defines the selected planning approaches and provides detailed descriptions of the selected methodologies. Section 4.2 contains the model formulations of the planning approaches.

4.1 Defining the planning approaches

This research uses the Integrated Production Planning and Scheduling (IPPS) approach to develop planning approaches (alternatives) to solve the tactical production planning problem. Chapter 2 assesses several useful planning techniques to develop IPPS approaches. Every planning technique has its advantages and disadvantages, which differ per production planning problem. For our production planning problem, it is important to develop a robust production plan that incorporates the sequence dependent changeover times, production capacity restriction, minimum production lot-sizes, multiple batch production lot-sizes, maximum production lot-sizes, inventory capacity restriction, best before date constraint, and service level constraint. The multiple batch size defines the allowed predefined production lot-size increase to incrementing the minimum production lot-size of a soft drink.

To optimize the tactical production planning problem, it is important to incorporate the sequence dependent changeover times, because the production sequence in a week and the selected soft drinks for production in a week affect the total changeover time. When incorporating the sequence dependent changeover times within the tactical production planning problem, it results in a full-space model that becomes hard to solve within acceptable computation time. Therefore, we use product families to develop planning approaches that solve the production planning problem in acceptable computation time. Therewith, it results in a better approximation of the total used changeover time, than planning approaches which use aggregated changeover times. Using product families make the planning approaches also willing to cluster soft drink of the same product family in a production week. In addition, changeover times between soft drinks of the same product family are lower than changeover times between soft drinks of different product family.

For this research, we select two planning techniques to develop planning approaches for the tactical production planning problem of Vrumona. Assessing the planning techniques discussed in Chapter 2, we decide to use the Mixed Integer Linear Programming (MILP) technique and a combination of the Adaptive Search (AS) technique together with the Simulated Annealing (SA) technique. The MILP formulation clusters product families by using binary variables and the AS technique assigns higher priorities to soft drinks of an already planned product family in the same production week. The AS algorithm constructs an initial production plan, which is improved by the SA algorithm that uses actual changeover times and changeover costs. We do not use the MILP algorithm together with the SA algorithm, because the power of MILP lies in optimizing the tactical production planning problem. Besides these two planning approaches, we assess a third planning approach, which uses the Advanced Planning (AP) software with actual changeover- and inventory costs rather than the currently used cost priorities.

This research compares the three developed planning approaches with the current planning approach. This results in a comparison of four planning approaches. In addition, we use a SA algorithm that defines the production sequences in a week with the lowest total changeover time. With this SA algorithm, we can compare the constructed production plans of the four planning approaches, because this algorithm defines the total used changeover time of a production plan by using the sequence dependent changeover times. Figure 12 shows the structure of the three developed planning approaches (alternatives). The upcoming three sections describe the production planning related parts of the three developed planning approaches. Section 4.1.4 describes the SA algorithm, which defines the production schedule of the constructed production plans.

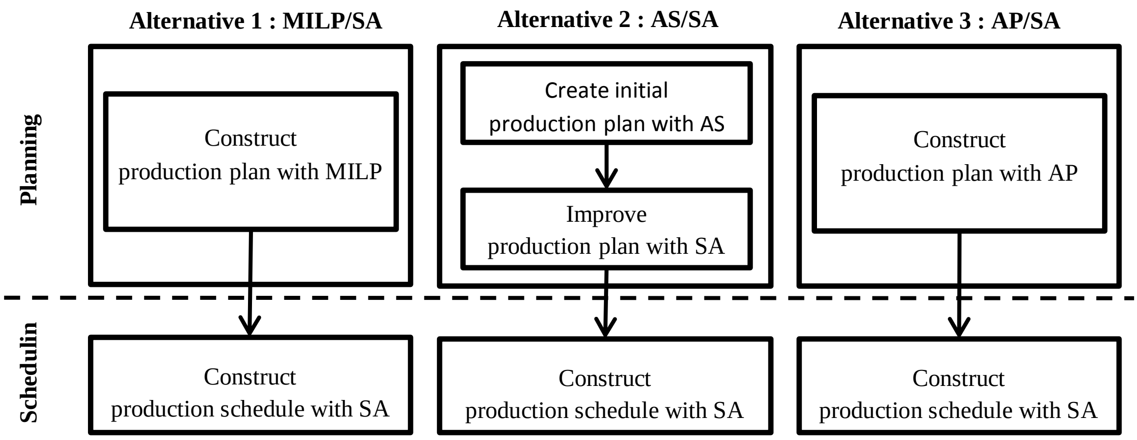


Figure 12 : Alternative structures

4.1.1 Alternative 1 – Mixed Integer Linear Programming approach

This planning approach uses a capacitated MILP formulation to solve the tactical production planning problem. Most of the productions planning methods construct a production plan based on average changeover costs and times. This planning approach uses two types of changeover costs and changeover times, namely product family changeover costs and times, and changeover costs and times for production changeovers within a product family. With these changeover costs and changeover times, this algorithm provides a better approximation of the used changeover time compared to the planning approaches that use average changeover times.

This MILP formulation uses a cost minimization objective to make a trade-off between changeover costs, internal inventory costs, external inventory cost, overtime costs, and backorder costs. The feasibility of the constructed production plan is secured with several constraints for the Syrup department, Packaging department and Logistic department. The advantages and disadvantages of this IPPS approach are:

Advantages

- Uses product families to define changeover times and costs more precisely.
- Uses internal storage capacity to penalize external storage (extra costs).
- Makes a trade-off between extra production capacity and extra storage capacity.

Disadvantages

- Large problems result in a long computation time to find an optimal solution.

4.1.2 Alternative 2 - Adaptive Search – Simulated Annealing approach

This planning approach uses the constructive Adaptive Search (AS) algorithm to construct an initial production plan that is optimized with the Simulated Annealing (SA) algorithm.

The AS algorithm uses probabilities based on priorities to select a candidate soft drink for production in a week. We define the priorities of the soft drinks as the initial inventory at the beginning of the week, divided by the sum of demand within the next seven weeks. The seven weeks for the summation of demand is defined, see Appendix G, by performing experiments with different number of weeks for the summation of demand. A soft drink with a high demand and a low inventory position retrieves a higher priority than a soft drink with low demand and a high inventory position. By using this definition of priorities, we assume that all soft drinks equally contribute to the profit of Vrumona.

The AS algorithm sequentially adds the selected soft drink to a week, until the total production time plus changeover time of the planned soft drinks reaches the available production capacity. With this planning rule, the algorithm consecutively adds soft drinks to the 26 weeks of the production plan. By changing the bias parameter α, the algorithm uses a more random selection approach or a more deterministic selection approach (Kolisch & Derlx, 1996). When the algorithm plans a soft drink of a product family, it assigns a 10 % higher priority to soft drinks of this product family in a week. This makes the algorithm eager to plan soft drinks of the same product family in a week. In addition, soft drinks can only be selected with an inventory position below a certain inventory level. This approach follows the same line of reasoning as the can-order level proposed by Silver et al. (1998).

The AS algorithm calculates production lot-size of planned soft drinks with the Economic Production Quantity (EPQ) formula. The algorithm uses aggregated changeover costs together with the year demand based on the average demand within the next seven weeks to calculate the production lot-sizes with the EPQ formula.

With information of the constructed production plan, the SA algorithm modifies the production weeks and production lot-sizes of a soft drink by using five shift rules. These shift rules increase or decrease the production lot-sizes, add a soft drink to a production week or subtract soft drinks from a production week, or exchanges two planned soft drink of different production weeks. The modified solution is called a neighbourhood solution. The SA algorithm randomly selects one of the shift rules to create a neighbourhood solution. The advantages and disadvantages of this IPPS approach are:

Advantages

- The AS algorithm clusters soft drinks of a product family.
- The SA algorithm improves the production sequences and production lot-sizes.
- The SA algorithm uses internal storage capacity to penalize external storage (extra costs).
- The SA algorithm makes a trade-off between extra production and extra storage capacity.
- Fast algorithm to solve complex problems.

Disadvantages

- The AS algorithm uses a deterministic approach to calculate the production lot-sizes.
- The AS algorithm does not use internal storage capacity to penalize external storage.

4.1.3 Alternative 3 - Current Advanced Planning (real costs) approach

This planning approach constructs production plans with the current planning software Advanced Planning (AP), but we use actual changeover costs and inventory costs rather than currently used cost parameters. To compare this planning approach with the other planning approaches, we plan the total period of 26 weeks and do not freeze the first four weeks of the production plan. The advantages and disadvantages of the currently used production planning approach are:

Advantages

- Fast algorithm to construct a production plan.

Disadvantages

- Uses an average changeover time per soft drink to define the used changeover time.
- Does not use internal storage capacity to penalize external storage (extra costs).
- Does not make a trade-off between extra production capacity and extra storage capacity.

4.1.4 Production schedule –Simulated Annealing

This research uses a Simulated Annealing (SA) algorithm that defines the production sequence, with the lowest total changeover time in a week, to compare the four planning approaches. This SA algorithm uses sequence dependent changeover times to construct the production schedule. In addition, the Syrup department and Packaging department have several anomalies on the general production sequence rules. The algorithm does not take into account these anomalies on the online operational scheduling level.

With the information of the production plan, the SA scheduling algorithm constructs the production schedule. This SA algorithm uses one shift rule that modifies the production sequence for a production week, by changing the sequence positions of two soft drinks with each other. The modified solution is called a neighbourhood solution. With a cost function, which uses the changeover costs and overtime costs, the algorithm calculates the objective value of a solution.

4.2 Models for the planning approaches

This section contains the detailed model description of Alternative 1 and Alternative 2. As mentioned before, we focus on cost reduction by sustaining the customer service level of 99.5%. Therefore, the objectives of the planning approaches are cost related. Both planning approaches first, solve the tactical production planning problem and second, construct an aggregated production schedule to define the production capacity utilization. The developed planning approaches use the MILP algorithm, and a combination of the AS algorithm together with the SA algorithm to solve the tactical production planning problem. These planning approaches can use overtime capacity at the end of the week for extra costs, attract external storage capacity for higher storage cost, and allow a certain amount of backorders for high costs.

Section 4.2.1 defines the general model assumptions. We use these general assumptions to develop the algorithm formulations for the planning approaches. Section 4.2.2 defines the indices, parameters, and variables needed to develop the planning approaches. Section 4.2.3 defines the planning approach that uses the MILP formulation (alternative 1). Section 4.2.4 defines the planning approach that uses the AS algorithm together with the SA algorithm (alternative 2) and Section 4.2.5 defines the SA algorithm that constructs the production schedule.

4.2.1 General assumptions

To develop the planning approaches, we made several assumptions, because modelling all anomalies of the Syrup department, Packaging department, and Logistic department results in a complex model that is too hard to solve. The planning approaches use constraints for: minimum production lot-sizes, maximum production lot-sizes, internal storage capacity level to penalize external storage, and maximum production capacity to construct a feasible production plan.

First, we assume that the minimum production lot-sizes secure the quality of the syrups and second, we assume the maximum production lot-sizes prevent obsolescence inventory. Third, we assume that the internal storage capacity levels provide a good approximation of the internally available storage capacity. The available storage capacity depends on types of stored soft drinks and the production lot-sizes. Therefore, we approximate the internal storage level for the soft drinks of a production line with the historic storage utilization in Appendix D.

Fourth, we assume that the forecasted demand provides the best representation of the actual sales in the near future and the soft drinks equally contribute to the profit of the company. Fifth, we assume that the safety stock levels for the soft drinks cover the uncertainty of the forecasted demand. Sixth, we assume that all soft drinks do equally contribute to the profit of Vrumona. Seventh, we assume that the operational measured production speed provides a good approximation of the production speed in the near future and eight, we assume that the available production capacity is free to use for production and does not result in additional costs. This results in eight assumptions to construct the planning approaches:

- The minimum production lot-sizes secure the syrup quality.
- The maximum production lot-sizes prevent obsolescence inventory.
- The internal inventory capacity level represents the trigger to store soft drinks externally.
- The forecasted demand represents the actual sales in the near future.
- The safety stocks cover the demand uncertainties.
- The soft drinks equally contribute to the profit.
- The deterministic production times cover for the production uncertainties.
- The available production capacity is free to use for production.

4.2.2 Indices, Parameters, Variables

To develop a MILP algorithm, AS algorithm, and SA algorithm, we define indices, parameters, and variables. The parameters values do not change, whereas the values of the variables are set by the algorithm. Most of the parameters and variables use indices which define the related activity, place, or time period. Our planning approaches use indices to define the soft drink type, product family, and production week. The number of soft drinks and product families differ per production line.

The solution space of the production planning problem becomes more complex when a production line contains more soft drink types and product families. This makes the tactical production planning problem harder to solve within an acceptable computation time. Beside the production line dependent indices, the planning approaches construct a production plan with the same number of production weeks for all production lines. This section defines the indices, parameters, and variables and the Sections 4.2.3 and 4.2.4 describe how the developed planning approaches use the indices, parameters, and variables. Section 4.2.5 defines the scheduling approach that also uses some of the indices, parameters, and variables.

INDICES

			# Prod. Line 4	# Prod. Line 10
i	Soft drinks	(i = 1 ….. N)	24	11
j	Product families	(j = 1 ….. M)	9	3
t	Production weeks	(t = 1 ….. T)	26	26

PARAMETERS

$MinSetup_i$	Minor changeover time (minutes) of soft drink i
$MaxSetup_j$	Major changeover time (minutes) of soft drink family j
$SetupTime_{ij}$	Sequence dependent changeover time (minutes) for soft drink j prior to soft drink i
$CostSMin_i$	Minor changeover costs of soft drink i
$CostSMax_i$	Major changeover costs of soft drink family j
$SetupCost_{ij}$	Sequence dependent changeover costs for soft drink j prior to soft drink i
$StartInv_i$	Initial inventory of soft drink i at the beginning of week 1
$ProTime_i$	Production time (minutes) for one unit of soft drink i
$Demand_{it}$	Demand of soft drink i in week t
$Capacity_t$	Available production time (minutes) in week t
$MinPRO_i$	Minimum production amount of soft drink i
$TierPRO_i$	Multiple batch lot-size increase of soft drink i
$MaxPRO_i$	Maximum production amount of soft drink i
Fam_{ij}	If 1 soft drink i belong to product family j , else 0
$MinInv_i$	Minimum weeks of inventory of soft drink i (Safety stock)
$MaxInv_i$	Maximum inventory of soft drink i (related to Best Before date)
$InvCapacity$	Available internal inventory capacity
$ExtICost$	External inventory storage costs per unit of soft drink i
$CostHold_i$	Inventory costs for one unit of soft drink i per year
$CostBack$	Penalizing costs for one unit of backorder
$CostOver$	Penalizing costs for one minute of overtime production

SA Parameters

β	Number of modified solutions per iteration.
τ_{start}	Start temperature
α	Decreasing factor of the temperature
τ_{stop}	Termination temperature

AS Parameters

α	Bias-parameter to define adaption technique (random, discrete)
θ	Number of demand weeks for summation

VARIABLES

XX_{it}	Continuous (0,inf)	Production quantity of soft drink i on in week t
PX_{it}	Binary (0,1)	Produce soft drink i in week t
PS_{ijt}	Binary (0,1)	Produce soft drink j prior to soft drink i in week t
IP_{it}	Continuous (0,inf)	Inventory level of soft drink i at the end of week t
IPE_{it}	Continuous (0,inf)	External inventory level of soft drink i at the end of week t
BL_{it}	Continuous (0,inf)	Backlog of soft drink i at the end of week t
XB_{it}	Integer (0,inf)	Number of multiple batch increase for soft drink i in week t
F_{jt}	Binary (0,1)	Produce family j in week t
O_t	Continuous (0,inf)	Overtime (minutes) production in week t
C_t	Continuous (0,inf)	Used production capacity in week t

SA Variables

SN_{Obj}	Continuous (0,inf)	Objective value of neighbourhood solution
SC_{Obj}	Continuous (0,inf)	Objective value of the current solution
SB_{Obj}	Continuous (0,inf)	Objective value of the best solution
Γ	Continuous (τ_{stop}, τ_{start})	Temperature used in an iteration
Γ_{prob}	Continuous (0,1)	Acceptance probability for a temperature iteration

AS variables

P_{it}	Continuous (0,inf)	Probability of soft drink i for week t
φ_{it}	Continuous (0,inf)	Priority of soft drink i for week t
R_{it}	Continuous (0,inf)	Regret-factor of soft drink i for week t

4.2.3 Alternative 1 – Mixed Integer Linear Programming approach

This section describes the Integrated Production Planning and Scheduling (IPPS) approach that uses the MILP technique to construct the production plan.

This production planning approach accounts for changeover costs and times related to product families. When a soft drink of a product family is assigned to a week, the changeover costs and time of this product family are assigned to the same production week. To define the used production capacity in a week, we use the product family changeover times, the non-family related changeover times, and the deterministic production speed.

The MILP formulation uses continuous variables for: production capacity, production lot-sizes, inventory position, backorder soft drinks, and overtime production. Besides these continuous variables, the algorithm uses binary variables to assign the changeover times and costs to a production week and the algorithm uses integer variables to model the multiple batch sizes (tiered production increases). The multiple batch size defines the allowed predefined production lot-size increase above the minimum production lot-size for a soft drink. This combination of binary, integer, and continuous variables make the model formulation a MILP formulation.

OBJECTIVE

The objective of our MILP formulation is to minimize the total changeover costs, inventory costs, overtime costs, and backorder costs. This planning approach allows a certain amount of backorders and allows a certain amount of overtime production for high costs. The planning approach penalizes backorders with high costs, because backorders affect the customer service level, and penalizes overtime production at the end of the week, because overtime production results in higher costs per production hour. The MILP formulation uses these costs parameters together with parameters for internal inventory costs, external inventory costs, product family changeover costs, and soft drink changeover costs to calculate the objective value of a solution. The MILP formulation uses the following cost minimization objective:

$$Minimize = \sum_{i=1}^{N}\sum_{t=1}^{T}(CostBack_i BL_{it} + CostSMin_i PX_{it}) + \sum_{t=1}^{T}\sum_{n=1}^{N}\frac{CostHold_i}{N} IP_{it} + \sum_{j=1}^{M}\sum_{t=1}^{T} CostSMax_j F_{jt} + \sum_{t=1}^{T}(ExtICost\ IPE_t + CostOver\ O_t)$$

CONSTRAINTS

To find a feasible solution within the production and inventory boundaries, this MILP formulation uses several constraints. The Constraints 4.1 and 4.2 account for the demand restriction and define the inventory level at the end of a week. To incorporate the initial inventory at the beginning of the current week (week 1), the Constraint 4.1 uses the parameter *StartInv*. The Constraint 4.1 accounts for the demand restriction and inventory level of the first week and Constraints 4.2 accounts for the demand restriction and inventory level of the production weeks 2 to 26. Constraint 4.3 defines the upper bound of the internal inventory capacity, which differs per production line. Constraint 4.4 defines the minimum inventory for a soft drink to cover the demand fluctuations and Constraint 4.5 defines the maximum inventory position based on the “Best Before” date. Note that Constraint 4.4 does not result in the desired outcome for environments with extreme demand and lead time fluctuations. Constraint 4.6 ensures that a limited amount of backorders is possible, which is related to the customer service level of 99.5%.

$$XX_{it} + StartInv_i + BL_{it} - IP_{it} = Demand_{it} \qquad \forall i, t = 1 \qquad (4.1)$$

$$XX_{it} + IP_{i(t-1)} + BL_{it} - IP_{it} - BL_{i(t-1)} = Demand_{it} \qquad \forall i, t > 1 \qquad (4.2)$$

$$\sum_{i=1}^{N} IP_{it} \leq InvCapacity + IPE_t \qquad \forall t \qquad (4.3)$$

$$IP_{it} \geq MinInv_i Demand_{it} \qquad \forall i, t \qquad (4.4)$$

$$IP_{it} \leq MaxInv_i \qquad \forall i, t \qquad (4.5)$$

$$\sum_{i=1}^{N} BL_{it} \leq 0.005 \sum_{i=1}^{N} Demand_{it} \qquad \forall t \qquad (4.6)$$

The Syrup department restricts the production lot-sizes with the minimum production lot-sizes, maximum production lot-sizes, and multiple batch size (tiered) increase. Constraint 4.7 ensures that the algorithm meets the minimum production lot-size restriction and Constraint 4.8 ensures that the algorithm meets the maximum production lot-size restriction. These two constraints also force the algorithm to assign the changeover costs of the planned soft drinks to the objective, with the use of a binary variable PX_{it}. In addition, the algorithm also uses this binary variable to assign the changeover times of the planned soft drinks to the used production capacity. Constraint 4.9 forces the algorithm to increase the production quantity with the predefined multiple batch sizes *TierPRO*$_i$.

$$MinPRO_i PX_{it} \leq XX_{it} \qquad \forall i, t \qquad (4.7)$$

$$XX_{it} \leq MaxPRO_i PX_{it} \qquad \forall i, t \qquad (4.8)$$

$$XX_{it} = MinPRO_i PX_{it} + TierPRO_i XB_{it} \qquad \forall i, t \qquad (4.9)$$

In order to account for the production capacity restriction, Constraint 4.11 restricts the used production capacity in week t with the available production capacity. It is possible to increase the production capacity at the end of the week, with the overtime production variable O_t, against extra costs. This constraint uses Constraints 4.10 to define whether the algorithm plans a product family in a week. Constraint 4.12 restricts the used overtime production capacity to the predefined maximum of one production day (1440 minutes).

$$F_{jt} \geq Fam_{ij} PX_{it} \qquad \forall i, j, t \qquad (4.10)$$

$$\sum_{i=1}^{N} ProTime_i XX_{it} + \sum_{i=1}^{N} MinSetup_i P_{it} + \sum_{j=1}^{M} MaxSetup_j F_{jt} \leq Capacity_t + O_t \qquad \forall t \qquad (4.11)$$

$$O_t \leq 1440 \qquad \forall t \qquad (4.12)$$

4.2.4 Alternative 2 - Adaptive Search – Simulated Annealing approach

This section describes the IPPS approach for Alternative 2, which uses the Adaptive Search (AS) algorithm to construct an initial production plan and uses the Simulated Annealing (SA) algorithm to improve this production plan.

4.2.4.1 Adaptive Search algorithm

The AS algorithm sequentially adds a selected soft drink to a production week, until the used production capacity exceeds the available production capacity, then the algorithm proceeds with the next production week. The algorithm recalculates for every iteration the priority, regret-factor, and probability of the soft drinks that have an inventory level below the can-order level. We specify the can-order level as the reorder-level plus an addition week of demand. The iterations relate to the allocation of a soft drink to a production week; when a soft drink is planned, the algorithm starts a new iteration.

The AS algorithm uses a demand related priority to randomly select a soft drink for production in a week. We define the priority of a soft drink as the inventory position at the beginning of a week divided by the forecasted demand for the next θ weeks. A higher value for the parameter θ accounts for a longer period of demand to anticipate on demand trends. As described, the algorithm uses the bias-parameter α to explore the solution space more deterministically or more randomly. The parameter α and parameter θ need to be initialized and tested to optimize this production planning approach.

The AS algorithm calculates the production lot-sizes of a planned soft drink with the Economic Production Quantity (EPQ). To define a feasible production lot-size for the planned soft drink, the AS algorithm starts with the minimum production quantity ($MinPRO_i$) and consecutively adds the multiple batch-size ($TierPRO_i$) to the production lot-size until it exceeds either the EPQ lot-size or the maximum production lot-size ($MaxPRO_i$).

In addition, we use a continuous variable to define the used production capacity and a binary variable to define whether a soft drink is produced in a week. With this binary variable, we assign the changeover times and costs to a production week. The subsection describes the variable function and algorithm structure of the AS algorithm.

VARIABLE FUNCTIONS

The AS algorithm uses several variable functions to construct a production plan. Function 4.13, 4.14, and 4.15 define how to calculate the values of the three variables, used by the algorithm to select a soft drink. Function 4.13 calculates the priority of a soft drink that differs per week. This function uses the parameter θ that defines the number of weeks for summation. We define the sum of demand for the weeks larger than T-θ as the last demand summation that can be computed with this function. Function 4.14 calculates the regret-factor, which uses the maximum of the soft drink priorities. Function 4.15 uses the regret-factors and the bias-parameter to calculate the priority of the soft drinks. Note that every iteration, the priorities, regret-factors, and probabilities need to be recalculated for the soft drinks with an inventory position below the can-order level. Appendix G defines the can-order levels.

$$\varphi_{it} = \begin{cases} \dfrac{IP_{it}}{\sum_{t}^{\theta+\mathrm{t}} Demand_{it}} & , t < T - \theta \\ \dfrac{IP_{it}}{\sum_{t=T-\theta}^{\mathrm{T}} Demand_{it}} & , t > T - \theta \end{cases} \qquad \forall i, t \qquad (4.13)$$

$$R_{it} = \max_{j \in \mathrm{N}} \varphi_{jt} - \varphi_{it} \qquad \forall i, t \qquad (4.14)$$

$$P_{ti} = \frac{(R_{it} + 1)^{\alpha}}{\sum_{i=1}^{\mathrm{N}} (R_{it} + 1)^{\alpha}} \qquad \forall i, t \qquad (4.15)$$

Function 4.17 computes the production lot-sizes. This function needs the average yearly demand of a soft drink, which is computed with Function 4.16. This function also uses the parameter θ that defines the number of weeks for summation. We define the value of D_{it} for the weeks larger than T-θ as the last D_{it} value that can be computed with this function. Function 4.18 defines the inventory level at the end of a week and Function 4.19 defines the total number of backorders at the end of the week. Function 4.20 computes the used production capacity. This function uses the sequence dependent changeover times and the deterministic production times.

$$D_{it} = \begin{cases} 52 \dfrac{\sum_{t}^{\theta+\mathrm{t}} Demand_{it}}{\theta} & , t < T - \theta \\ 52 \dfrac{\sum_{t=T-\theta}^{\mathrm{T}} Demand_{it}}{\theta} & , t > T - \theta \end{cases} \qquad \forall i, t \qquad (4.16)$$

$$X_{it} = \sqrt[2]{\frac{2PX_{ij}SetupCost_{ij}D_{it}}{HoldingCost_i}} \qquad \forall i, t, \; j = pred(i) \qquad (4.17)$$

$$IP_{it} = max(0, IP_{i(t-1)} + X_{it} - BL_{i(t-1)} - Demand_{it}) \qquad \forall i, t \qquad (4.18)$$

$$BL_{it} = min(0, IP_{i(t-1)} + X_{it} - BL_{i(t-1)} - Demand_{it}) \qquad \forall i, t \qquad (4.19)$$

$$C_t = \sum_{i=1}^{N} \sum_{j=1}^{M} SetupTime_{ij} PS_{ijt} + \sum_{i=1}^{N} ProTime_i XX_{it} \qquad \forall t \qquad (4.20)$$

ALGORITHM STRUCTURE

To define how the AS algorithm uses the parameters and variables to construct a feasible production plan, we describe the structure of the algorithm. Before each selection of a soft drink, the algorithm recalculates the priorities, regret-factors, and probabilities. The algorithm randomly selects a soft drink and calculates the production lot-size with the EPQ for this selected soft drink. With the minimum production lot-size ($MinPRO_i$), multiple batch size increase ($TierPRO_i$), and maximum production ($MaxPRO_i$), the algorithm selects the closest feasible production lot-size.

Figure 13 shows the algorithm structure of the AS algorithm. Besides this algorithm structure, the algorithm uses three additional rules. The first additional rule, the algorithm assigns a high priority to the soft drinks of an already assigned product family to the same production week. These soft drinks receive a 10% higher priority. The second additional rule, the algorithm can only select soft drinks with and inventory position below a certain can-order level and the third additional rule, the algorithm cannot assign soft drinks twice to a production week.

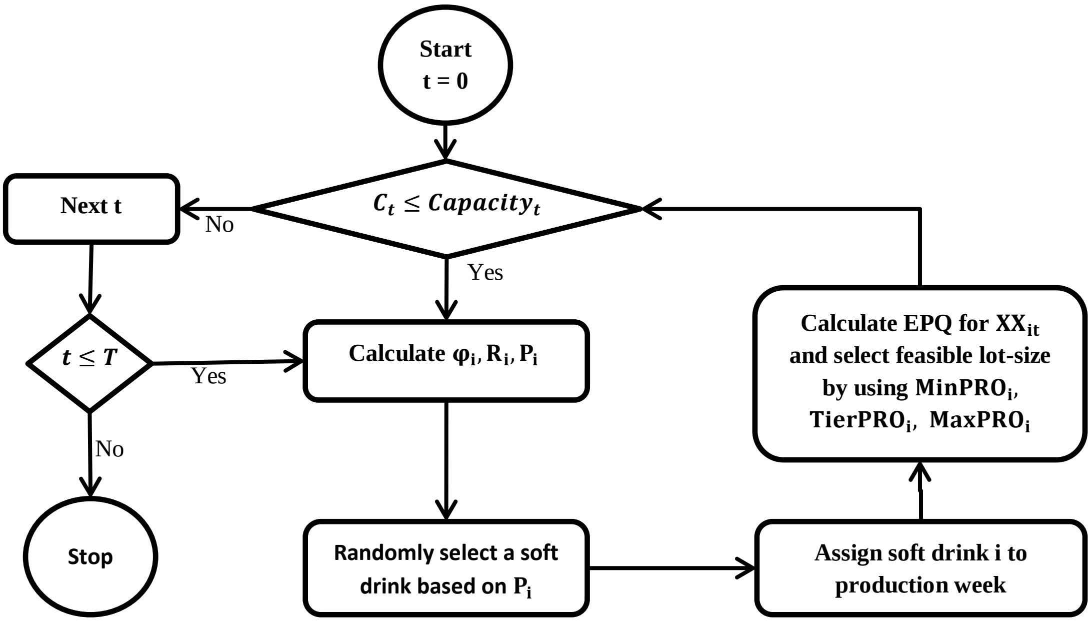


Figure 13: Adaptive Search algorithm structure

4.2.4.2 Simulated Annealing algorithm

This section describes the Simulated Annealing (SA) algorithm to improve the initially constructed production plan, by taking into account the sequence dependent changeover times and costs. With the sequence dependent changeover times, the SA algorithm provides a more accurate approximation of the used changeover capacity.

The SA algorithm uses parameters that define the planned production lot-sizes, changeover costs, changeover times, internal storage capacity level, externally storage costs, available production capacity and overtime production costs. Beside these parameters, the SA algorithm uses four parameters to improve the initially constructed production plan. These four parameters are: the start temperature τ_{start}, termination temperature τ_{stop}, decreasing factor α, and number of shifts per temperature iteration β. The four parameters need to be initialized to construct feasible and near optimal solution for the production planning problem within the shortest amount of calculation time.

The SA algorithm uses shift rules that modify the production lot-sizes and the production sequence over the weeks. This modified solution is called a neighbourhood solution. The algorithm calculates the objective value of a solution with the same cost parameters as the MILP formulation. In addition, we use constraints that secure the feasibility of the production plan. This section discusses the variable function and the SA algorithm structure.

VARIABLE FUNCTIONS

The SA algorithm uses variable functions to modify the initially constructed production plan. Function 4.21 uses the backorder costs, the inventory costs, the external storage costs, the overtime costs, and the changeover costs to calculate the objective value of a production plan. This objective function uses Function 4.22 to calculate the number of externally stored soft drinks, Function 4.18 to define the inventory position, and Function 4.19 to define the number of backorders. Function 4.23 calculates the temperature decrease for the next iteration. Function 4.24 calculates the temperature related acceptance probability and Function 4.25 defines the used overtime production capacity at the end of a production week.

$$SN_{Objective} = \sum_{i=1}^{N}\sum_{t=1}^{T} CostBack_i BL_{it} + \sum_{i=1}^{N}\sum_{t=1}^{T}\left(\frac{CostHold_i}{N}\right) IP_{it} + \sum_{t=1}^{T}(ExtICost\, IPE_t + CostOver\, O_t) + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j=1}^{M} SetupCost_{ij} P_{ijt} \tag{4.21}$$

$$IPE_t = max(0, \sum_{i=1}^{N} IP_{it} - InvCapacity) \tag{4.22}$$

$$\Gamma = \Gamma\alpha \tag{4.23}$$

$$\Gamma_{prob} = e^{\frac{(SC_{Obj} - SN_{obj})}{\Gamma}} \tag{4.24}$$

$$O_t = max(0, \sum_{i=1}^{N}(\sum_{j=1}^{M}(SetupTime_{ij} PS_{ijt}) + ProTime_{it}) - Capacity_t) \tag{4.25}$$

ALGORITHM STRUCTURE

To define how the SA algorithm uses the parameters and variables to improve the initially constructed production plan, we describe the structure of the algorithm. This SA algorithm uses five shift rules to modify the initially constructed production plan. These shift rules modify the production lot-sizes of the planned soft drinks, exchange the production lot-sizes of different weeks with each other, adds a soft drink to a production week, or delete a soft drink to a production week. The SA algorithm uses the following five shift rules:

- Exchange two planned production lot-sizes of different production weeks.
- Increase the production lot-size of a soft drink with the multiple batch size ($TierPRO_i$).
- Decrease the production lot-size of a soft drink with the multiple batch size ($TierPRO_i$).
- Add a soft drink to a production week with the minimum production lot-size ($MinPRO_i$).
- Delete a soft drink from a production week.

To create neighbourhood solutions, this algorithm randomly selects one of the shift rules. The algorithm accepts a neighbourhood solution, when the neighbourhood solution has an objective value SN_{Obj} lower than the objective value of the current solution SC_{Obj}. Otherwise the algorithm can accept a neighbourhood solution with an acceptance probability Γ_{prob}, which can be calculated with Function 4.23. The algorithm stores the neighbourhood solution as best solution, when the neighbourhood solution has also an objective value lower than the objective value of the best solution so far SB_{Obj}. When the algorithm does not accept the neighbourhood solution, the algorithm restores the current solution to reverse the made modifications.

Each temperature iteration, the algorithm performs β modifications, before the algorithm decreases the temperature, with Function 4.22, for the next temperature iteration. The algorithm terminates when the temperature reaches the termination temperature τ_{stop}. Figure 14 shows the structure of the SA algorithm.

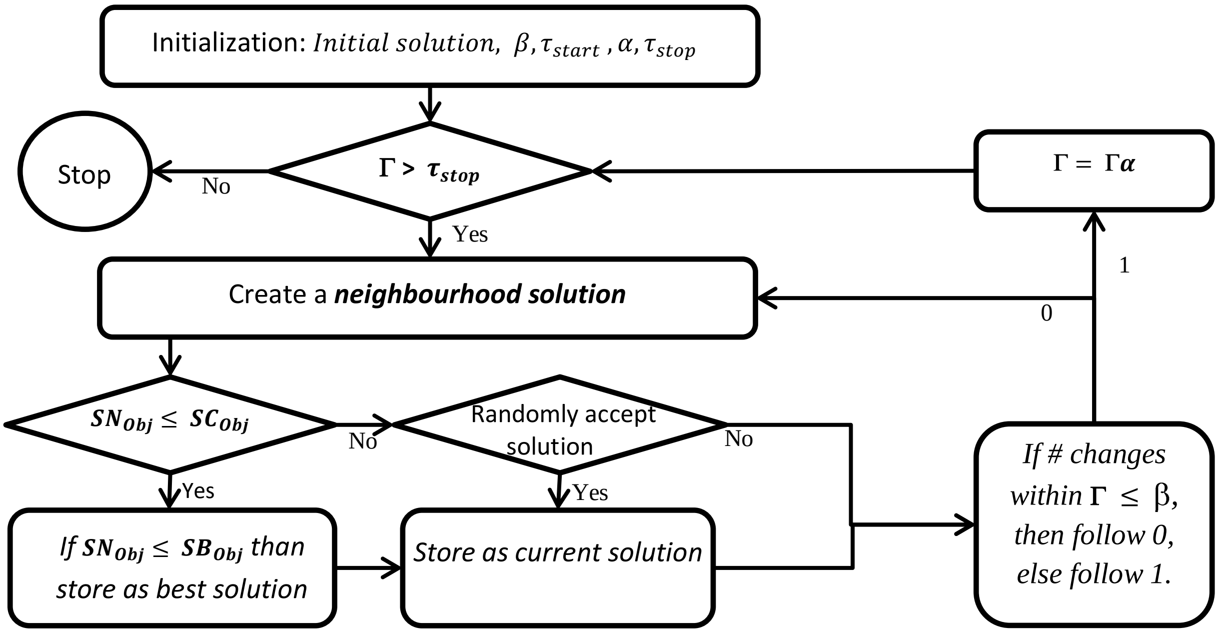


Figure 14 : Simulated Annealing algorithm structure

4.2.5 Production schedule - Simulated Annealing

This section describes the Simulated Annealing (SA) algorithm that constructs production schedules for the four planning approaches, with the information of the constructed production plans. The SA algorithm improves the production sequence for the production weeks, by using the sequence dependent changeover times to define the total changeover time of a production plan. The algorithm generates the initial production sequence, by randomly assigning the soft drinks of the production plan to the production sequence of the same production week.

This SA algorithm uses the same four parameters as the SA algorithm of Alternative 2 to modify the initial solution. These four parameters need to be initialized to construct a feasible and near optimal solution for the production scheduling problem within the shortest amount of calculation time. Besides these parameters, the algorithm uses the sequence dependent changeover costs and the overtime production costs to calculate the objective value of a solution. With one shift rule, the algorithm exchanges two soft drinks within the same production week.

VARIABLE FUNCTIONS

The SA algorithm uses four variable functions to improve the production schedule. Function 4.26 uses the sequence dependent changeover costs and the overtime costs to calculate the objective value. Furthermore the algorithm uses the Function 4.23, 4.24, 4.25 to calculate respectively the temperature decrease, the temperature related acceptance probability, and the used overtime costs.

$$SN_{Objective} = \sum_{t=1}^{T}(\sum_{i=1}^{N}(\sum_{j=1}^{M} SetupCost_{ij}PS_{ijt}) + CostOverO_t) \tag{4.26}$$

ALGORITHM STRUCTURE

To define how the SA algorithm uses the parameters and variables to improve the initial production schedule, we describe the structure of the algorithm. With the uses of one shift rule to modify the production sequence within a week, the algorithm creates a neighbourhood solution. The algorithm structure is equal to the algorithm structure of the SA algorithm of Alternative 2, see Figure 14.

The differences between the SA algorithm to improve the production plan and the SA algorithm to improve the production sequence for the production weeks, are the shift rules and the objective functions. The SA algorithm of Alternative 2 uses five different shift rules to modify the current solution and this SA algorithm uses one shift rule to modify the solution. In addition, this algorithm uses the sequence dependent changeover costs and overtime costs to calculate the objective of a solution.

5 Alternative assessment and experimental structure

This chapter describes the experimental structure and performance measures for the comparison of the planning approaches. Section 5.1 provides the experimental structure of this research. Section 5.2 defines the performance measures and assesses the performance of the planning approaches on these performance measures. Section 5.3 draws the conclusion of this chapter and selects the most suitable planning approach.

5.1 Experimental structure

This section describes the experimental structure, in order to compare the alternatives. Alternative 1 and 2 use actual costs to construct a production plan. The currently used production planning AP software does not use real cost to make a trade-off between production- and inventory costs. Therefore, we define a third alternative that uses real costs parameters for production- and inventory costs. With this alternative, we show how the AP algorithm constructs production plans with actual costs. The three alternatives together with the current planning approach result in a comparison of four planning approaches.

For comparison of the planning approaches, we use eight experiments per planning approach. The experiments are divided in two clusters. The first cluster, planning approaches construct the production plans for calendar weeks 1 to 4 of 2012 and the second cluster, planning approaches construct the production plans for the calendar weeks 14 to 17 of 2012. We select these eight weeks for our experiments, because the first cluster has to deal with low sales volumes and the second cluster has to deal with high sales volumes for both production line. In addition, we decided to use a four weeks cluster, because this shows how production lot-sizes change within the four weeks scheduling period. We perform for production line 10 only experiments for the calendar weeks 14 to 17, because this production line has excessive production capacity in each week.

These experiments use the available data at the beginning of a week. We need to update the forecasted demand, the initial inventory positions, and available production capacity for every experiment week. The initial inventory positions for the calendar weeks 1 and 14 are the actual inventories at the beginning of these weeks in 2012. The initial inventory positions for the other experiment weeks relate to the constructed production plan of the previous week. To define the initial inventory position, we use actual sales data.

5.2 Performance assessment

This section defines performance measures to compare the planning approaches (alternatives). To define these performance measures, we use production planning literature and currently used performance indicators of Vrumona. As shown in the research problem, cost reduction and customer service level are the most important performance measures for the alternatives assessment. Although these are the core performance measures of this research, we define several other performance measures to make a more weighted comparison of the planning approaches. This results in the following performance measures:

- Average costs /week
- Customer service level (first week)
- Backorders (within first four weeks)
- Capacity utilization

    - Average overtime capacity/week (hours)
    - Average changeover capacity/week (hours)
    - Average idle capacity/week (hours)
- Changes to the production lot-sizes (within the first four weeks)
- Production changeovers/week
- Average external storage capacity/week
- Flexibility to demand fluctuations (qualitative measure)
- Impact to Syrup department (qualitative measure)
- Impact to Packaging department (qualitative measure)
- Impact to Logistics department (qualitative measure)

The performance measure “Average costs/week” calculates the average of inventory costs, changeover costs, and overtime production costs over the 13 weeks production planning period. The total costs do not include backorder costs, because we use these costs to penalize backorders and these are not real costs. The performance measure “Customer service level” uses actual sales of 2012, to define how much soft drinks cannot be delivered to the customers within the first week of the production plan. We use Function 5.1 to calculate the service levels of the constructed production plans. In addition, the number of backorders can be computed with Function 4.17.

$$Service\ Level = \left(1 - \frac{Total\ sales\ of\ week\ 1 - backorders\ of\ week\ 1}{Total\ sales\ of\ week\ 1}\right) * 100\% \qquad (5.1)$$

To compute the actual inventory level for the 13 weeks of the planning period, we use forecasted demand. The performance measure “Backorders” uses the inventory positions of the first four weeks to define the performance over the scheduling period. The number of backorders is compared with the forecasted sales within the first four weeks, to define the percentage contribution of the backorders. We use only the first four weeks of data, because for the four weeks scheduling period, the production lot-sizes are frozen.

The capacity performance measures “Average changeover capacity /week” and “Average idle capacity/ week” show how effectively the planning approaches use the available production capacity. The changeover times and idle production capacity do affect the production line utilization, so it does affect the Operation Performance Indicator (OPI) measure. The OPI measure shows the operational performance of the production lines. The performance measure “Average overtime capacity/week“ shows how much overtime capacity the planning approaches use to construct the production plan. We use these three performance measure together with the average production time per week to define the capacity utilization for the 13 weeks of the constructed production plans.

The performance measure “Changes to the production lot-sizes” assesses the stability of the constructed production plan. The planning approaches construct a 13 weeks production plan. The changes to these production lot-sizes within these 13 weeks affect the material planning process. This performance measure defines the percentage changes of the production lot-sizes as percentage change to the production lot-sizes for the weeks 4 and 17 within the two experiment clusters (four weeks), because the longest lead-time of raw materials is four weeks.

The performance measure “Production changeovers/week” shows how much production changeovers the production plan uses on average per week. The production changeovers per week also affect the OPI measure of the production department, because an increase of the number of production changeovers can increase the uncertainty of the production lines.

The performance measure “Average external storage capacity/week” defines the needed external storage capacity for the 13 weeks of the production plan. For this measure, we use the forecasted demand to calculate the total inventory at the end of a week. The costs for the externally stored soft drinks are added to the inventory costs, which are used to calculate the total costs.

The other four performance measures are qualitative performance measures. To assess the performance of the planning approaches on these qualitative performances, we discuss the qualitative results of the constructed production plans with the employees of the related departments. In addition, we use the quantitative performance measures to undermine the qualitative performance measures, to assess the planning approaches.

5.2.1 Quantitative performance assessment

This section assesses the performance of the planning approaches on the six quantitative performance measures. First, we assess the performance of the planning approaches for production line 4 and second, we assess the performance of the planning approaches for production line 10.

Quantitative performance on production line 4

The total sales of soft drinks for production line 4, contributed for 11.5% to the total sales of Vrumona in 2012. Therefore, improvements to the production plan can lead to a large cost reduction. With the average costs per week, Figure 15 shows that the production plans of the currently used approach “AP/SA” and the planning approach “AP/SA (real costs)” result in the highest average costs per week for the weeks 1 to 4. The production plans of the planning approach “AS/SA” result in lower average costs per week for the weeks 1 to 4, in comparison with the current planning approach. For the weeks 14, 15, and 16, this planning approach constructs production plans with significantly higher costs than the other planning approaches. The planning approach “MILP/SA” outperforms the other planning approaches on this performance measure for all eight expiriment weeks.

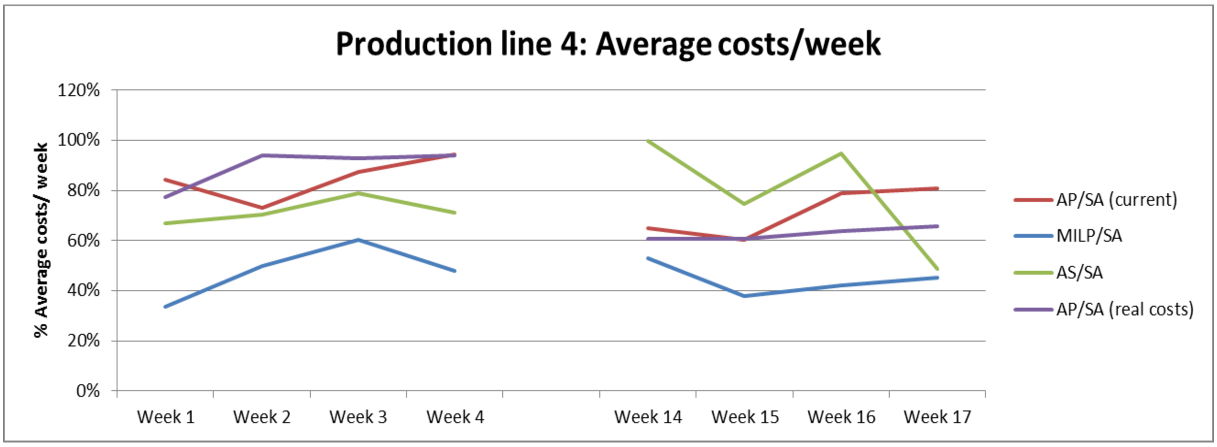


Figure 15: Average costs per week (Production line 4)

The average costs per week of the constructed production plans consists of changeover costs, inventory costs, external inventory costs, and overtime capacity costs. Figure 16 shows the percentage cost contributions for the planning approaches per cost category. The cost contributions for the production plans of the planning approaches “AS/SA”, “AP/SA (real costs)”, and “AP/SA” show that the higher average costs per week, especially relate to the number of externally stored soft drinks. The production plans of the planning approach “MILP/SA” use the external storage capacity as little as possible. In addition, all planning approaches use overtime capacity, but the production plans of the planning approach “AS/SA” result in the highest overtime cost contribution.

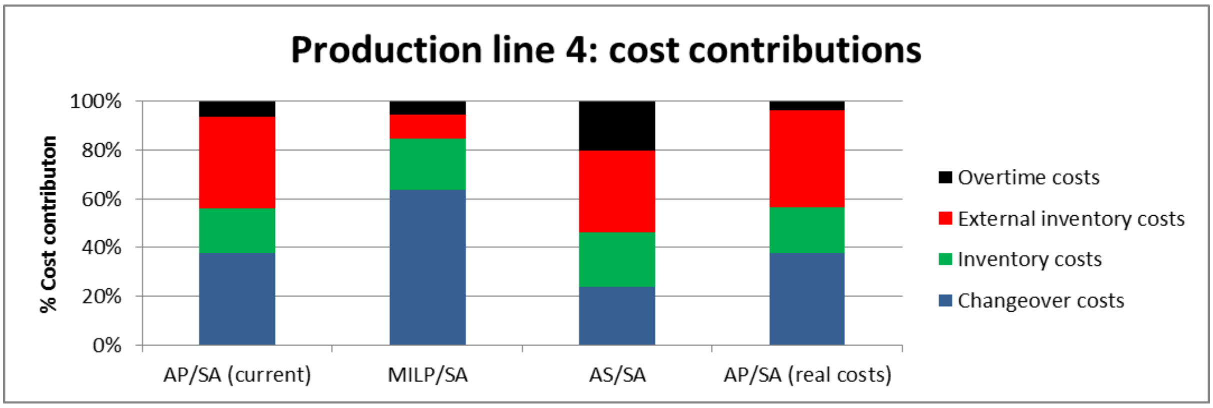


Figure 16: Cost contribution (production line 4)

The customer service level performance measure defines how the planning approaches fulfil the actual customer demand in the first week of the production plan. Figure 17 shows the customer service levels of the four planning approaches. The production plans of the planning approaches “MILP/SA”, “AS/SA”, and “AP/SA (real costs)” for the weeks 1 to 4 achieve a customer service level of 100%. The customer service level of the currently used approach “AP/SA” for week 3 is below 100%, with a service level of 96%. Besides the customer service levels of these weeks, the production plans of the planning approach “MILP/SA” for the weeks 14 to 17 achieve customer service levels of 100%. The planning approach “AS/SA” has low customer service levels for the weeks 15 and 16, with respectively 88% and 93.4%. This planning approach works with larger production lot-sizes, which make it difficult to fulfil demand in weeks with high demand and limited production capacity. The production plan of the planning approach “AP/SA (real costs)” for week 16 achieves a service level of 90.8%.

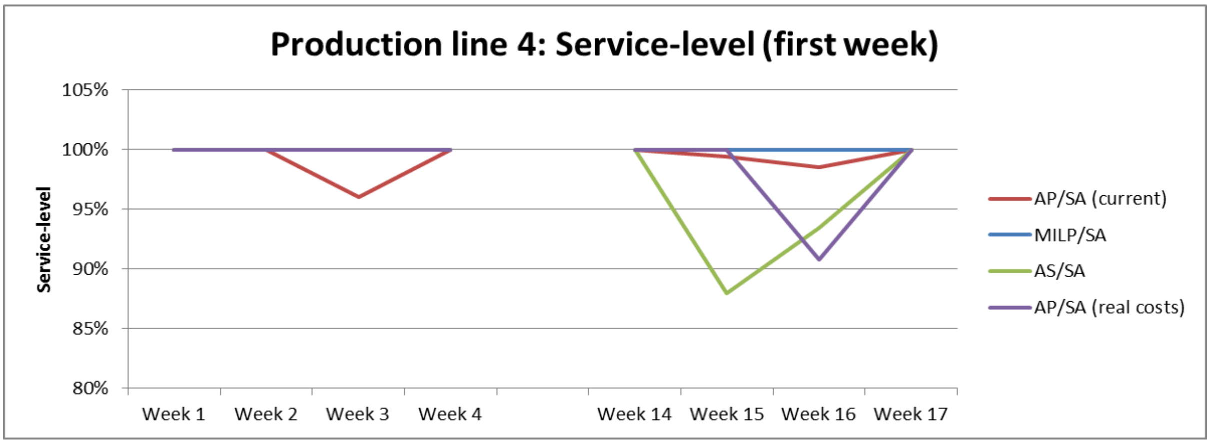


Figure 17: Service level (production line 4)

With the total backorders within the first four weeks of the production plan, we show how the planning approaches anticipate on demand changes within the first four weeks of the scheduling period. Figure 18 shows the total backorders within the first four weeks. The planning approach "MILP/SA" constructs production plans with zero backorders for seven of the eight experiments. Only the production plan of week 15 results in a small number of backorders. The production plans of the planning approach "AS/SA" and the current planning approach "AP/SA" result in a large number of backorders for the weeks 14 to 17. For the weeks 1 to 4, only the production plans of the current planning approach "AP/SA" result in backorders.

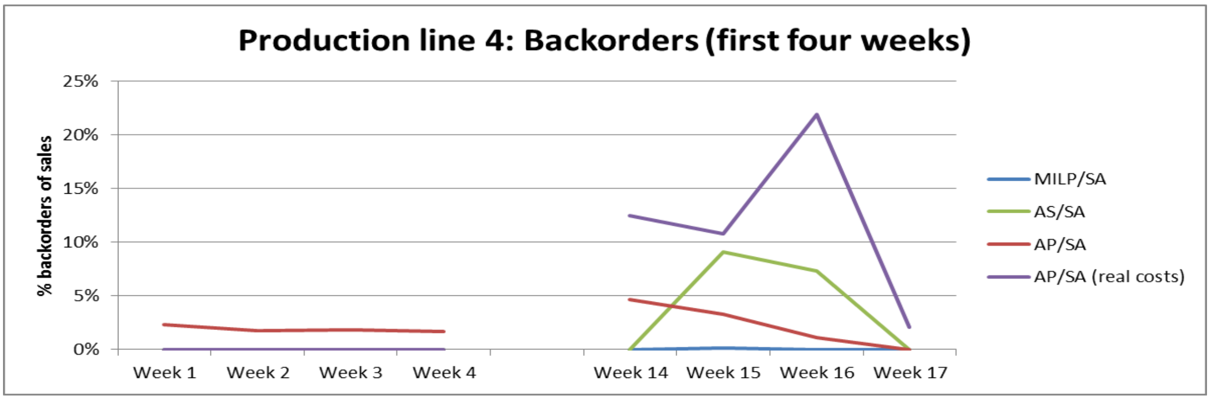


Figure 18: Total backorders within first four weeks (production line 4)

With the average costs per week and the service level performance measures, we cannot show how the planning approaches use the available production capacity to construct a production plan. To define the production capacity utilization per constructed production plan, we use the values of average idle capacity, average changeover capacity, average production capacity, and average overtime capacity.

The average capacity utilization of the four planning approaches, see Figure 19, shows that the production plans results in a higher utilization of the production capacity for the weeks 14 to 17, than for the weeks 1 to 4. The planning approaches use more production capacity in the weeks 14 to 17, because these weeks cope with high demand and limited production capacity.

The production plans of the planning approaches for the weeks 1 to 4 use on average 0.3% overtime production capacity. The production plans for the weeks 14 to 17 show a largest difference between the planning approaches on the overtime production capacity utilization, where the planning approaches "AP/SA" and "AS/SA" use respectively 1% and 3.6% overtime production capacity. The planning approaches "MILP/SA" and "AP/SA (real costs)" use on average 0.5% overtime production capacity. The planning approach "AS/SA" uses the largest amount of overtime capacity for the weeks 14 to 17, although the production plans result in low customer service levels for these weeks.

The production planning approach "AP/SA" uses the least changeover capacity, with an average of 16.2% changeover capacity contribution to the production capacity utilization. When we compare the used changeover capacity of the planning approach "MILP/SA" with the used changeover capacity of the planning approach "AP/SA", the planning approach "MILP/SA" uses on average 4% more changeover capacity. The planning approaches "AP/SA" and "AP/SA (real costs)" use on average 18.7% of the production capacity for production changeovers and the planning approach "MILP/SA" uses on average 19.4% of the production capacity for production changeovers.

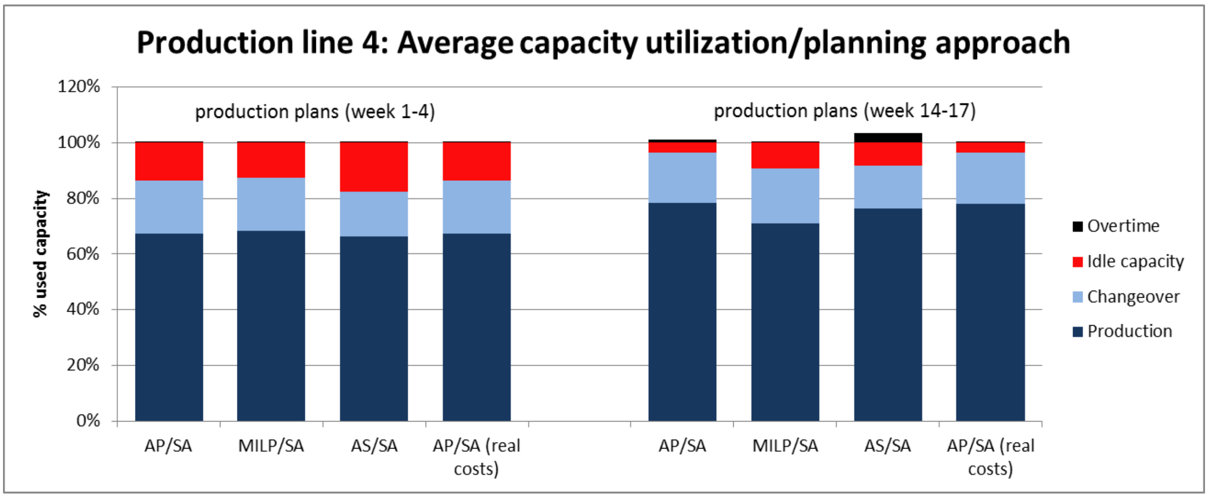


Figure 19: Production capacity utilization/planning approach (Production line 4)

The average costs contain the costs for externally stored soft drinks. Some of the planning approaches use a large amount of external storage capacity to fulfil the customer demand. Figure 20 shows the average externally stored soft drinks for the constructed production plans. This figure shows that the planning approaches “AP/SA”, “AP/SA (real costs)”, and “AS/SA” use a high amount of external storage capacity to fulfil the customer demand. In the weeks with limited production capacity, weeks 14 to 17, the average number of externally storage soft drinks is lower than the weeks with excessive production capacity. The planning approach “MILP/SA” uses the least external storage capacity to fulfil the customer demand.

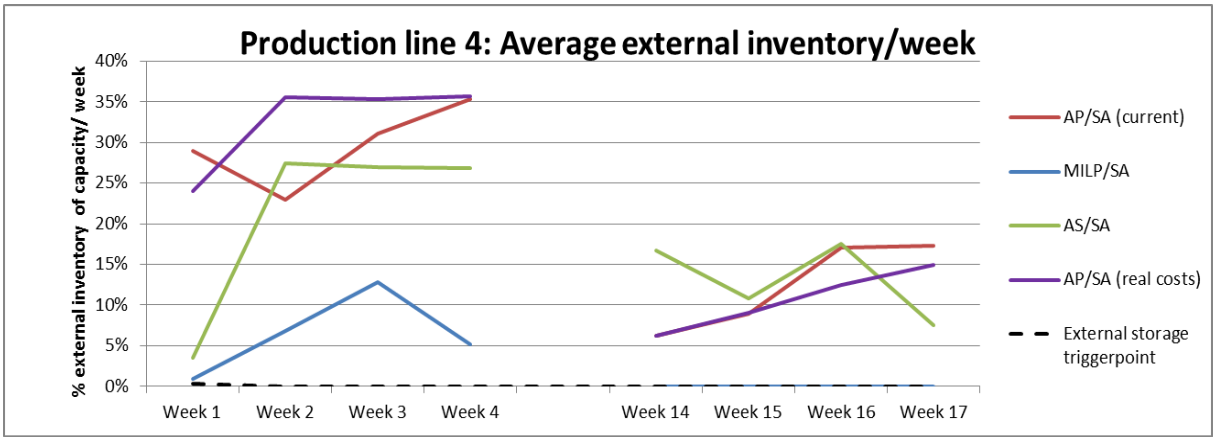


Figure 20: Percentage external inventory of internal inventory capacity/week (Production line 4)

The average production changeovers per week, see Figure 21, show how much production changeovers the planning approaches plan per week. The planning approach “AS/SA” plans larger production lot-sizes, which results in a 50% lower number of production changeovers per week in comparison with the other planning approaches. The planning approach “MILP/SA” plans in the weeks 14 to 17 on average one production changeover more, than the current planning approach.

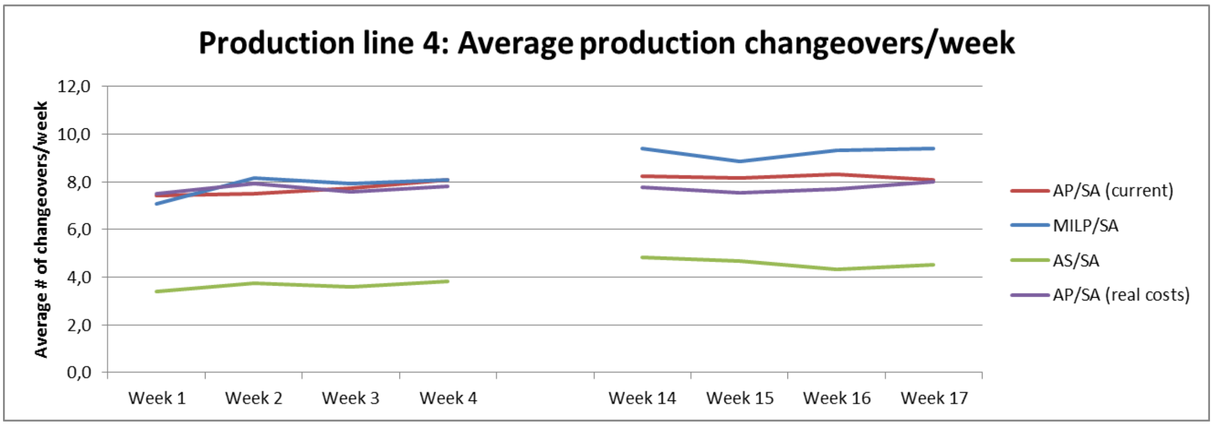


Figure 21 : Average planned productions/week (production line 4)

Quantitative performance on production line 10

The total sales of soft drinks of production line 10, contributed around 2% to the total sales of Vrumona in 2012. Improvements to the production plans for this production line do not result in the largest cost reduction, but it shows how the planning approaches construct a production plan for production lines with no constraining production capacity. Figure 22 shows the average costs per week for the weeks 14 to 17. The production plans of the planning approach “AS/SA” and the planning approach “AP/SA (real costs)” for week 14 result in the highest average costs per week. The average costs per week of the planning approach “AP/SA (real costs)” are higher for all experiment weeks, in comparison with the other planning approaches. The average costs per week of the planning approach “AS/SA” for the weeks 15 to 17 are almost equal to the average costs per week of the current planning approach “AP/SA”. The planning approach “MILP/SA” has lower average costs per week for the experiment weeks, in comparison with the other planning approaches.

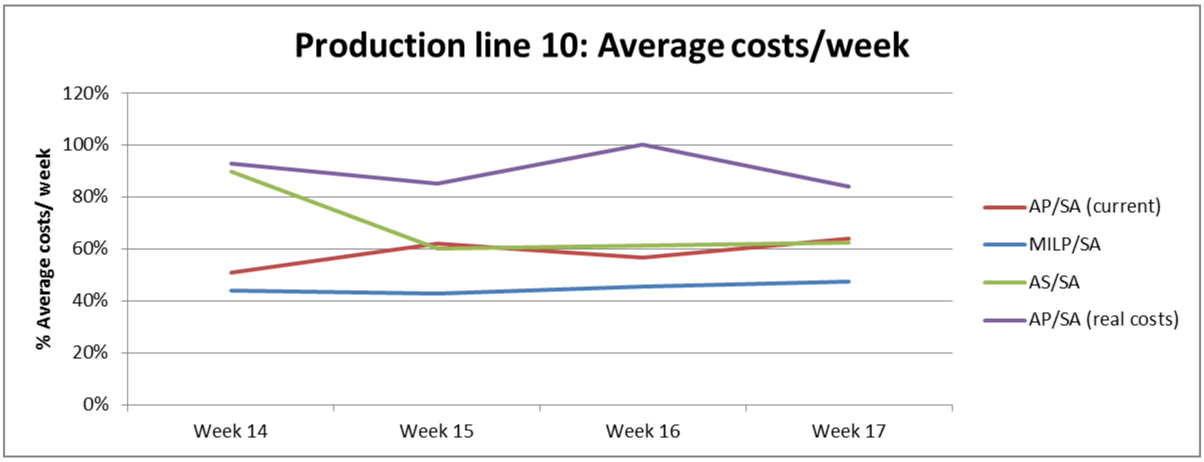


Figure 22: Average costs per week (Production line 10)

Figure 23 shows the cost contributions of the constructed production plans with the planning approaches. The planning approaches “MILP/SA” and “AS/SA” do not use overtime capacity and external storage capacity. Both current planning approaches do use overtime capacity to construct the production plans. In addition, the current approach “AP/SA” uses external inventory capacity. The planning approach “AP/SA (real costs)” uses the highest amount of external storage capacity. The inventory- and changeover costs contribute most to the average costs per week, for all planning approaches.

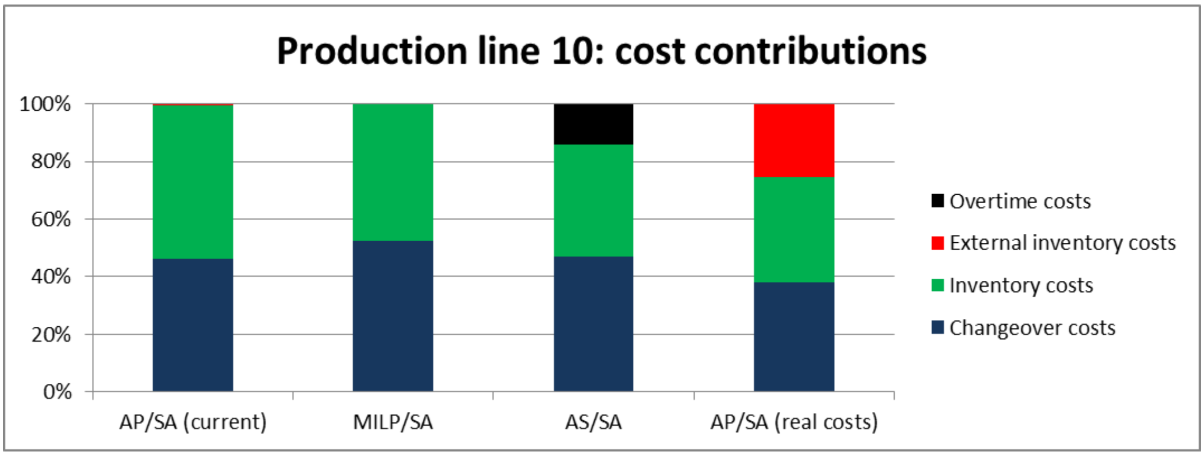


Figure 23: Cost contribution (production line 10)

The customer service levels of the planning approaches, see Figure 24, show that the planning approaches "MILP/SA" and "AS/SA" outperform the current planning approach. The customer service level of the current planning approach "AP/SA" only achieves a 100% customer service level for week 17 and the planning approach "AP/SA (real costs)" achieves a 100% customer service level for the weeks 16 and 17. The constructed production plans of these planning approaches achieve customer service levels of respectively 78.5% and 80.2% for week 15. The planning approach "AP/SA (real costs)" achieves a 87.5% customer service level for week 16. In addition, the planning approach "AP/SA" constructs production plans with the highest amount of backorders in the first four weeks of the production plans, see Appendix H. The planning approaches "MILP/SA" and "AS/SA" construct production plans that fulfil all forecasted customer demand within the first four weeks of the production plans. The planning approach "AP/SA (real costs)" constructs production plans with a small number of backorders in the first four weeks of the production plans.

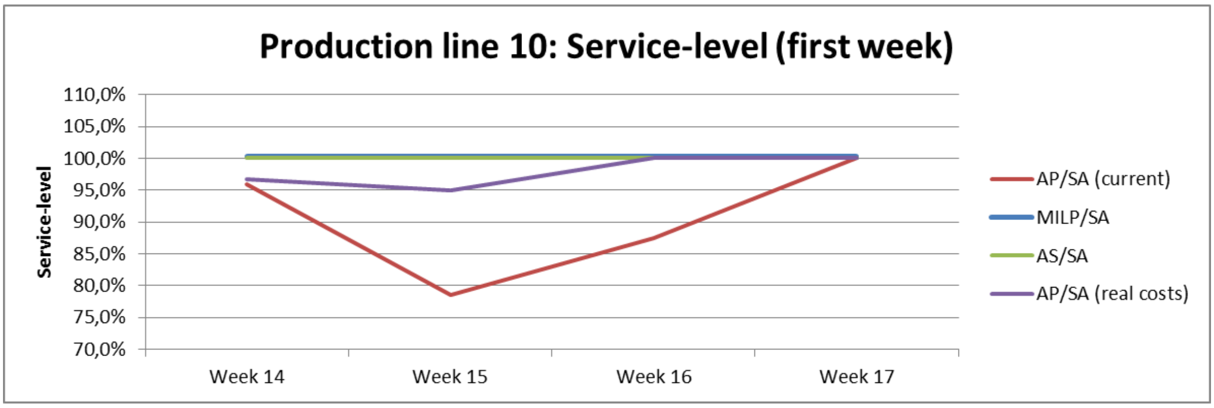


Figure 24: Service level within first week (production line 10)

Production line 10 has excessive production capacity to fulfil the demand of the soft drinks. The average production capacity utilization for the production plans of the planning approaches, see Figure 25, shows that all planning approaches use at most 55% of the available production capacity. In addition, the production plans of the planning approaches "AP/SA" and "AP/SA (real costs)" use on average 5% of the production capacity for production changeovers and the production plans of the planning approaches "MILP/SA" and "AS/SA" use on average 4% of the production capacity for production changeovers.

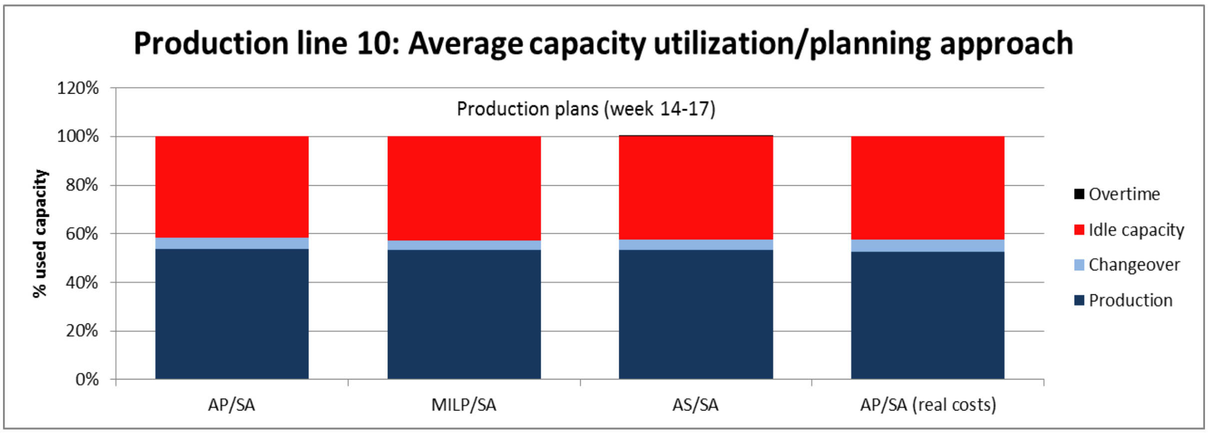


Figure 25: Production capacity utilization per planning approach (Production line 10)

The production plan of the current planning approach "AP/SA", see Figure 26, show that these production plans use a little external inventory capacity. The planning approach "AP/SA (real costs)" uses the highest amount of external storage capacity, in comparison with the other planning approaches. The planning approaches "MILP/SA" and "AP/SA" use zero external storage capacity.

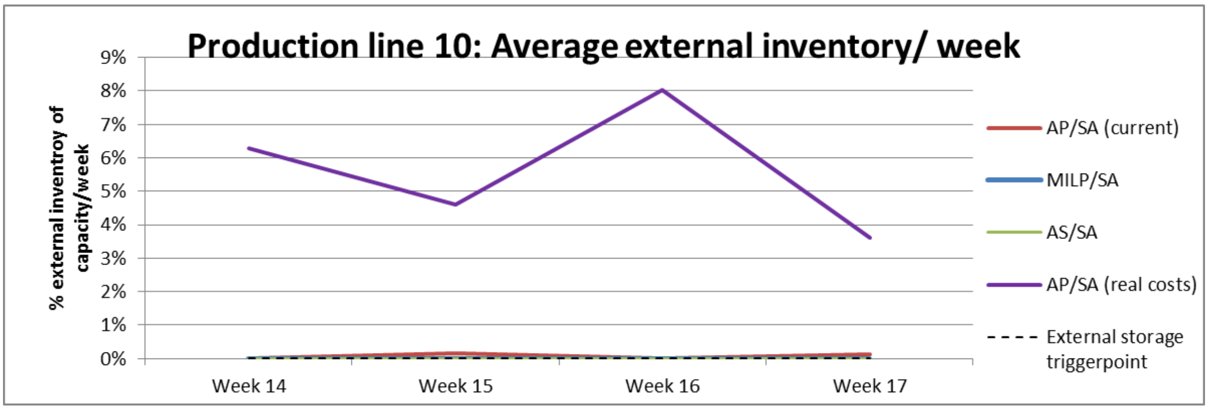


Figure 26: Percentage external inventory of internal inventory capacity/week (Production line 10)

Figure 27 shows the averaged planned productions per week. The planning approach "AS/SA" works with larger production lot-sizes than the other planning approaches, so this result in a lower number of changeovers per week. In addition, the planning approach "MILP/SA" combines the soft drinks of a product family, but plans more changeovers in a week. This higher number of changeovers does not result in a higher changeover capacity.

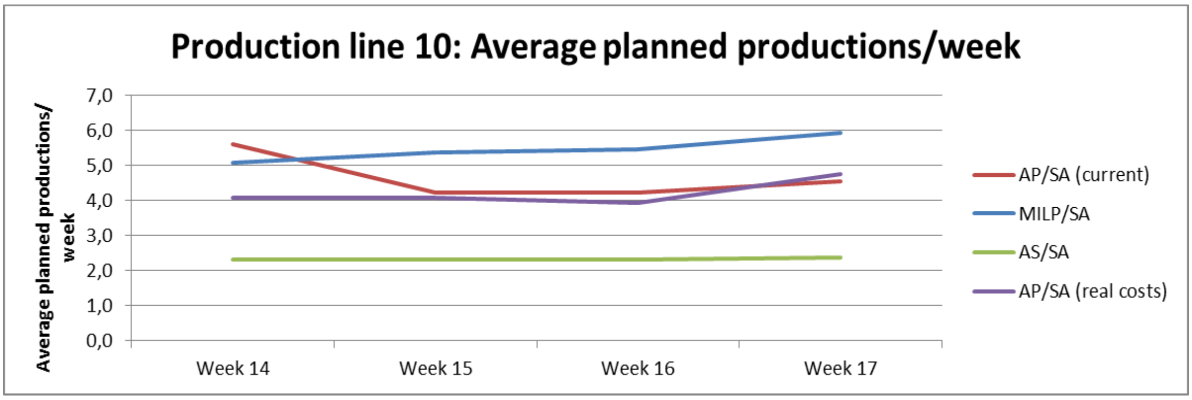


Figure 27: Average planned productions/week (production line 10)

5.2.2 Qualitative performance assessment

This section qualitatively assesses the planning approaches on the flexibility to demand fluctuations and the impact to the related departments, for production line 4 and production line 10. We discussed the quantitative results of the planning approaches, with employees of the related departments and management of Vrumona.

Flexibility to demand fluctuations

We conclude that the constructed production plans show flexibility to demand fluctuation, when the constructed production plans have idle production capacity, because the production planner can use this production capacity to plan additional demand.

The constructed production plans for production line 4 of the four planning approaches do not fully utilize the available production capacity in weeks with excessive production capacity. In the weeks with limited production capacity, only the planning approach "MILP/SA" has idle production capacity for the first weeks of the production plans. All constructed production plans for production line 10 have on average 40% idle production capacity, so the production planner can use this production capacity to anticipate on demand fluctuations. To conclude, the planning approaches "AP/SA", "AS/SA", and "AP/SA (real costs)" are less flexible to demand fluctuations in periods with limited production capacity, than the planning approach "MILP/SA".

Impact to the Syrup department

The higher number of production changeovers cause smaller production lot-sizes, which affect the efficiency of the Syrup department. Smaller production lot-sizes can affect the quality of produced syrups. Only the planning approach "MILP/SA" plans smaller production lot-sizes than the current planning approach "AP/SA". We conclude that the production lot-sizes of the constructed production plans with the planning approach "MILP/SA" do not affect the syrup quality, because the planning approaches secure the syrup quality with the minimum production lot-sizes.

Impact to the Packaging department

A higher number of production changeovers per week increases the uncertainty of the packaging production process. The planning approach "MILP/SA" uses on average one production changeover more per week in periods with limited production capacity, than the planning approaches "AP/SA" and "AP/SA (real costs)". This higher number of production changeovers can negatively affect the reliability of the production lines. In addition, the planning approach "AS/SA" plans on average 50% less production changeover per week, in comparison with the current planning approach "AP/SA". This can positively affect the reliability of the production lines. In dialogue with the production department, we conclude that the reliability of the production lines is not significant affected by the planning approaches.

Impact to the Logistic department

The Logistic department is equipped with storage lanes to store small production lot-sizes and large production lot-sizes. Large production lot-sizes utilize several storage lanes. Therefore, the Logistic department can handle an increased number of small production lot-sizes, as an increased number of large production lot-sizes. The increased number of small production lot-sizes of the planning approach "MILP/SA" and the increased number of large production lot-sizes of the planning approach "AS/SA" do not affect the efficient utilization of the storage lanes.

The amount of externally stored soft drinks affect the finished goods handling activities of the Logistic department, because the Logistic department has to transport these soft drinks to the external warehouse. When these externally stored soft drinks are needed, the Logistic department has to transport the soft drinks from the external warehouse to the onsite warehouse. The planning approach “MILP/SA” uses the least amount of external storage. Therefore, we conclude that this planning approach positively affect the Logistic handling activities of the Logistic department.

5.3 Conclusion planning approaches assessment

The planning approach “MILP/SA” outperforms the other planning approaches on the most important performance measures: total costs and customer service level. Figure 28 shows the estimate cost reduction of the four planning approaches, on both the production line 4 and 10.

Saving potential

Production line 4	Estimate total cost (full year)	Estimate cost-reduction
Current : AP/SA	100%	0%
Alternative 1 : MILP/SA	59%	41%
Alternative 2 : AS/SA	97%	3%
Alternative 3 : AP/SA (real costs)	97%	3%
Production line 10	**Estimate total cost (full year)**	**Estimate cost-reduction**
Current : AP/SA	100%	0%
Alternative 1 : MILP/SA	77%	23%
Alternative 2 : AS/SA	117%	-17%
Alternative 3 : AP/SA (real costs)	155%	-55%

Figure 28: Saving potential of the planning approaches

The planning approach “MILP/SA” accomplishes an estimate cost reduction of 41% for production line 4 and an estimate cost reduction of 23% for production line 10, on the tactical planning level, when we compare this planning approach with the currently used planning approach “AP/SA”. In addition, only the planning approach “MILP/SA” achieves a 100% customer service level for the eight experiment weeks.

The higher costs for the other three planning approaches especially relate to externally stored soft drinks. The two planning approaches, related to the current planning approach, do not use an internal storage capacity level to penalize externally stored soft drinks for higher costs. Therefore, the production plans of these two planning approaches store a high amount of soft drinks externally. The planning approach “AS/SA” constructs a production plan with larger production lot-sizes, than the current planning approach. These larger production lot-sizes result in a higher amount of externally stored soft drinks. The planning approach “AS/SA” also needs extra production capacity to fulfil the customer demand, which results in high costs due to overtime production capacity.

The current planning approach “AP/SA”, and the planning approaches “AS/SA” and “AP/SA (real costs)” do not achieve a 100% customer service level for the experiment weeks. The average customer service levels over the eight experiment weeks are below the target of 99.5%, so these planning approaches do not perform in accordance with the high customer service level of Vrumona and also do not result in the largest cost reduction.

Besides the high performance on these performance measures, the planning approach “MILP/SA” uses on average 4% more changeover time than the current planning approach “AP/SA” uses for production line 4. This is the result of one extra production changeover in weeks with more constraining production capacity. In addition, the effect of the smaller production lot-sizes and the increased number of changeover does not result in a significant impact to the departments. Meanwhile, the lower amount of externally stored soft drinks for the planning approach “MILP/SA” results in less handling activities for the Logistic department.

We address the planning approach “MILP/SA” as the best planning approach for the tactical production planning problem of Vrumone, because this planning approach solely performs in accordance with the high customer service level of Vrumona and achieves the largest estimate cost reduction over a full year.

6 Conclusions and recommendations

This chapter provides an answer to the main research question. Section 6.1 provides the conclusions of the research. Section 6.2 defines how Vrumona can implement the best planning approach. Section 6.3 addresses research recommendations. Section 6.4 addresses the limitations of this research and Section 6.5 describes subjects for further research.

6.1 Conclusions

Currently, the software tool Advanced Planning (AP) constructs the production plan. This software tool uses cost priorities and production related constraints, but does not account for the total available inventory capacity constraint and sequence dependent changeover times. The constructed production plans result in backorders of soft drinks, the production planner has to modify the production lot-sizes and production week of the soft drinks to fulfil the customer demand. In this research we show how Vrumona can minimize their production costs plus inventory costs by maintaining the current service level, with an improvement of the production planning approach. For this research, we define the following research question:

> *How can Vrumona structurally improve their production planning approach to minimize the production- and inventory costs, while maintaining a customer service level of 99.5%?*

This research defines three planning approaches for the production planning process of the Supply Chain Planning department and compares these planning approaches with the currently used planning approach. One of the developed planning approaches relates to the currently used planning approach, but uses actual costs instead of the currently used cost priorities. The other two developed planning approaches use an Integrated Production Planning and Scheduling (IPPS) approach to construct production plans. These IPPS approaches work with product families, which result in a more precise calculation of the changeover time per week and make the planning approaches more willing to combine the soft drinks of the same product family in a week, to reduce the total changeover time. In addition, the IPPS planning approaches use an internal inventory capacity level constraint, which defines when the total stored soft drinks requires external storage, resulting in extra costs. These approaches can extend the available production capacity, resulting in extra costs.

The planning approach “MILP/SA” outperforms the other planning approaches on the most important performance measures of Vrumona: total costs and customer service level. Planning approach “MILP/SA” accomplishes an estimate cost reduction of 41% for production line 4 and an estimate cost reduction of 23% for production line 10, on the tactical planning level, when compared to the currently used planning approach “AP/SA”. The production plans for the experiment weeks of the planning approach “MILP/SA” achieve a 100% customer service level. This planning approach solely performs in accordance with the high customer service level standard of Vrumona and achieves the largest cost reduction. Therefore, we recommend the planning approach “MILP/SA” as the best planning approach for the tactical production planning problem of Vrumona.

Planning approach “MILP/SA” plans on average one extra production per week, in weeks with high demand and constraining production capacity and uses on average 4% more changeover capacity, compared to the current planning approach “AP/SA”. The planning approach “MILP/SA” does not significantly affect the Syrup department and Production department. In addition, this planning approach uses the lowest amount of externally stored soft drinks, which positively affects the number of handling activities for the Logistic department.

6.2 How to implement the selected planning approach

This section defines how Vrumona can implement planning approach “MILP/SA”. The current planning software Advanced Planning (AP) uses the same mathematical technique to solve the tactical production planning problem, which can be customized with the new knowledge provided by this research.

The results of the planning approaches show that externally stored soft drinks contributes significantly to the higher cost for the other planning approaches, than for the planning approach “MILP/SA”. With this knowledge about the tactical production planning problem, we conclude that the internally available inventory capacity does constrain the production lot-sizes and production weeks of the production plans, because large production lot-sizes result in a large number of externally stored soft drinks. Therefore the current planning tool AP should account for higher external storage cost when the total inventory in a week exceeds the storage capacity level.

Apart from this knowledge about the production planning problem, the results also show that for some weeks it is profitable to use extra production capacity to fulfil the customer demand to keep the number of externally stored soft drinks low. By adding this constraint to the algorithm in the AP software, the algorithm can make a trade-off between overtime costs and external storage costs.

The outcome of the planning approaches shows that algorithms can better calculate the total changeover time per week, when they work with product families. The production changeover times between soft drinks of the same product family are much lower than the changeover times between soft drinks of different product families. Furthermore, these product families make the planning approach more willing to plan soft drinks of the same product family in a week.

Accounting for these constraints increases the algorithms complexity. This results in a longer computation time to construct a production plan. The large cost reduction and high service level of the planning approach “MILP/SA” show that this longer computation is worth improving the production planning process.

6.3 Research recommendations

Vrumona wants to have a stable production plan within the first four weeks, to order raw materials for production. Therefore, we recommend freezing production lot-sizes of the scheduled soft drinks of the first week, and solely freeze production weeks of the soft drinks within weeks 2 till 4 of the production schedule in the production plan. Within weeks 2 till 4 of the production schedule, AP can modify production lot-sizes to fulfil the customer demand.

Second, we recommend defining changeover costs, overtime capacity costs, internal inventory costs, external inventory costs, and backorder costs for all production lines, so this planning approach can also be used for the other production lines. To define the changeover costs for a product family and the changeover costs for production changeovers within a product family, it is important to define product families. In addition, it is important to update these costs periodically, for example yearly.

Third, we recommend showing the cost impact in the scheduling software Advanced Scheduling (ASI), when the production planner modifies production lot-sizes and production week. The ASI software foresees production lot-sizes and production weeks of the planned soft drinks within the next 13 weeks, and production sequence for the first four weeks. ASI can use these parameters together with the costs to show the cost impact of changes to the production schedule.

6.4 Research limitations

The planning approaches use deterministic forecasted demands and production speeds as input to be able to construct the production plans. These deterministic data does not account for the uncertainties of the real world. The planning approaches do not account for the extra production lot-sizes needed to cover the soft drink losses or erroneous productions of soft drinks. In the current situation the production planner increases planned production lot-sizes or plans new production lot-sizes to cover these losses and uncertainties.

6.5 Subjects for further research

In the future, simultaneously solving the tactical production planning problem for the production lines that share both the same labour resources can be studied to optimally distribute the production capacity over these production lines. The available labour resources for these production lines define the available production capacity. Currently, the available production capacity is arbitrarily divided over the production lines to construct the production plan, Vrumona does not know whether this results in the best production capacity division. When AP can decide how to distribute the available production capacity, it can result in a cost reduction. In addition, defining the production capacity and defining the demand forecast are equally important, because the available production capacity restricts the planning approach to construct a production plan.

Another subject for further research can be, redesigning the storage areas of the Logistic department to store smaller production lot-sizes efficiently. Currently, the Logistic department is designed to shelve small production lot-sizes and large production lot-sizes. The smaller production lot-sizes of the selected production planning approach can lead to a less efficient utilization of the storage capacity.

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Appendix

A. Research methodology

This chapter provides an overview of the research methods used for the research. This research follows the research methodology structures of the Managerial Problem Solving Method of Heerkens (2005) and the Design Science Methodology of Wieringa (2010). To do an extensive and structural literature research, we use the Five-Stage Grounded-Theory of Wolfswinkel et al. (2013).

Used research methodologies

To structure the research process of the paper we use the Managerial Problem Solving Method of Heerkens (2005) together with the Design Science Methodology of Wieringa (2010). According to Heerkens (2005) the research problem we are facing is an action problem, because this research changes the current practice of the production planning in order to realize the defined norm (cost reduction). Furthermore, Heerkens (2005) addresses seven research stages in order to define an answer on the main research problem. Wolfswinkel (2010) conclude that a research consists of an engineering cycle that defines the research problem and method, and a research cycle that acquires the knowledge.

In the early phase of the research, we lack of important information about the research problem and especially about the causes and effects of the problem. To gather this information, the main problem is divided into smaller better manageable sub-problems (Heerkens, 2005).

Literature search

This research uses a literature review methodology to retrieve necessary information about the production planning methods and cost analysing methods. Several search engines are available to find the relevant articles. These search engines containing thousands of articles in different research fields. To retrieve the relevant articles out of these available articles, we use the Five-Stage Grounded-Theory of Wolfswinkel et al. (2013). They develop interactive literature search steps to gather relevant literature. The first step is the most important one, where the inclusion/exclusion and search terms are defined. For our literature search we focus on literature about the production planning, production scheduling, and cost structure methods.

To ensure a structural literature research, we use the following search engines: Scopus and Web of Science. Both search engines are widely used in the field of Organizations and Management, and use clear inclusion and exclusion criteria to find relevant articles. By searching for production planning or production scheduling articles, the literature search in Scopus results in over 7000 articles. With the inclusion of the search criteria “optimization”, the literature search results in 2600 articles. For this literature search we use the following search string:

"Production planning" OR "production scheduling" AND "optimization"

We exclude the articles before 2000 and review the residual articles on their relevance. This results in a selection of ten relevant articles. Three of these articles focus on the food and beverage industry and the other seven articles investigate integrated solution strategies or production planning algorithm for production planning and scheduling. By using these articles for forward and backward search, we found other relevant articles. The forward search reveals articles that refer to these articles and the backward search reveals articles, where these articles refer to. In addition, out of these articles we define new search terms, to extend our literature search to find specific literature about optimization methods for the production planning.

Throughout the paper, we use several other articles to support our analysis and give answers to the sub-questions. To find these articles, we use the same literature search methodology.

B. Production scheduling rules

Priorities to make a production plan per production line:

Production line 1: 1.5 litre PET bottles

- Start the production with the bottle type the production is ended with the previous week.
  - Green bottle or Pepsi bottle
- Cluster the same bottle types.
- Cluster soft drinks that use the same syrup.
- Cluster 4-packs or 6-packs.

Production line 2: 0.5 litre, 1 litre and some 1.5 litre PET bottles (except Sourcy water and 4-packs)

- Start the production with the bottle type the production is ended with the previous week.
  - Bottles 0.5 litre, 1 litre or 1.5 litre (different shapes of bottles)
- Cluster soft drink with same bottle.
- Cluster preforms with the same colour.
- Cluster soft drinks that use the same syrup.
- Constraint: If the 1.5 litre green bottle is in production on line 1, it cannot be produced simultaneously on line 2.

Production line 3: 33cl cans

- Preferred to start the production at the beginning of the week with Sourcy waters.
  - Production sequence from low PH to high PH.
- Preferred to end the week with Lipton soft drinks:
  - Production line needs a linger cleaning, which is also needed at the end of the week
- Cluster soft drinks that use the same syrup.
- Cluster production runs with same packaging quantity.
  - Trays of 24-cans or trays with six 4-pack cans

Production line 4: 20cl glass bottles for OoH industry.

- Preferred to start the production at the beginning of the week with Sourcy waters.
  - Production sequence from low PH to high PH.
- Cluster soft drinks which need the pasteurizer.
  - Production line 5 uses same pasteurizer. Soft drinks that need the pasteurizer cannot be scheduled simultaneously on production line 4 and 5.
- Preferred to end the week with Pepsi Cola.

Production line 5: 75cl and 100cl glass bottles for OoH industry.

- Only produce one type of bottle in a production week.
  - Bottle types: Piet Boon 75cl, Pure 75cl and Sourcy 100cl.
  - Bottle changeover takes four hours, which cannot be done by the operators.
- Cluster soft drinks which need the pasteurizer.
  - Production line 4 uses same pasteurizer. Soft drinks that need the pasteurizer cannot be scheduled simultaneously on production line 4 and 5.
- Schedule production line 6 after production line 5.
  - Production line 6 uses the same crates washer,

Production line 6: PRB bottles 1 litre and 1.5 litres for food service industry.

- Only produce one type of bottle in a production week.
  - Bottle types: 1 litre and 1.5 litre
  - Bottle changeover takes four hours.
- Production sequence from low PH to high PH.
- Schedule production line 6 after production line 5.
  - Production line 5 uses the same crates washer.
- Preferred to end the week with Pepsi Cola.

Production line 7: Bag in Bock (BiB) for food service industry.

- Preferred to start the week with Pepsi Cola
  - Syrups for BiB are different to the syrups for the other production lines.
- Preferred to end the week with Lipton soft drinks.
  - Production line needs a Loog cleaning, which takes a longer time and should always be done at the end of the week.

Production line 9: Tetra cartons 20 cl (3 x 6-Pack).

- End the week with soft drinks that contain yoghurt.
- Cluster soft drinks that use the same syrup.

Production line 10: Production of 20cl bottles for food service industry.

- End the week with soft drinks containing yoghurt.
- Cluster soft drinks with the same syrup.

Unwritten rules the Production planner takes care of:

- Preferred to start the week with Sourcy Blue or Pepsi Regular
  - Because the Syrup department needs to clean all production lines and start up the production of syrup at the beginning of the week. The syrup for Pepsi Regular is directly available for production. Before the production of Sourcy Blue, the production line needs two Loog cleaning. This cleaning process is needed for all production lines at the start of the week.
- Preferred to end the production of the week with Pepsi Regular, allowed to stop production.
- Start with soft products and end with hard products (End of the week)
- Produce (plan in advance) to cover the demand in this revision week/maintenance days
- Plan the tomato juice at the end of the week, when tomato juice is produced in a week.
  - Tomato juice uses the same valve as Apple juice and need a 24 hour homogenization process before it can be processes on the production lines.

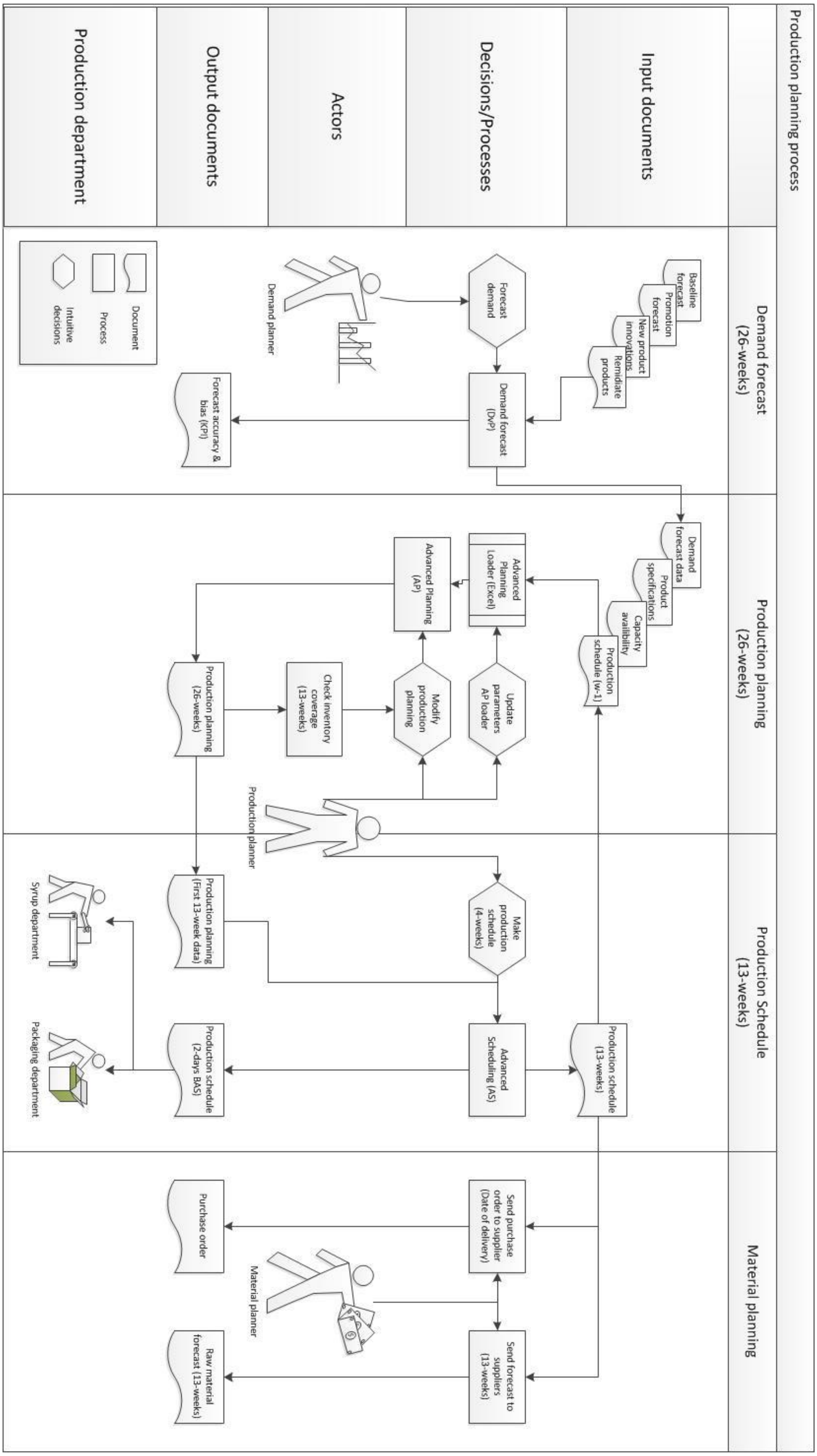

Figure A : Production planning processes

C. Workforce planning

The production of soft drinks is a continuous production process, wherefore workforce for the Syrup department, Packaging department and Logistic departments is 24 hours a day available. To define the labour costs, we define how much operational employees are available per production line and how much employees are available for the logistic activities.

Packaging department

As describe in the main text of this paper, the workforce planning for the production departments are made in advance. This workforce planning is divided into three production clusters, which are allocated to production lines. On average five days a week and 24 hours a day, workforce is available for production. To determine the operation labour costs for a production line over a year, we defined the average number of employees whom work for a production line and define the production lines allocated to the production clusters. Table A shows these numbers of the workforce planning for the production department.

Table A: Workforce Schedule Production Department

Workforce Schedule Production Department

Planned workforce

Cluster / shift (# FTE)	Morning	Afternoon	Night
Cluster 1	8	8	8
Cluster 2	8	8	8
Cluster 3	8	8	8
Siroop department	3	3	3
Total # FTE	13 until 16	12 until 15	7
Total # shifts per week	5	5	5

Workforce cluster for Production line

Cluster / Production line	1	2	3	4	5	6	7	9	10
Cluster 1	•	•				1/2			
Cluster 2				•	•	1/2			
Cluster 3			•				•	•	•
Siroop department	•	•	•	•	•	•	•	•	•
Avg # FTE / line	3,0	3,0	3,5	7,0	8,0	7,0	1,0	1,5	1,5

Logistic department

The workforce planning for the logistic department consists of several logistic areas. These logistic areas support the storage of soft drinks for one or more production lines. Because all operational labour costs for the logistic department are allocated to one cost centre, we defined the average number of employees whom work for the logistic activities to determine the material handling labour costs per production line. The workweek of the logistic department starts on Sunday at 8 PM and ends at Saturday at 7 AM. Table B shows the workforce planning for the logistic department.

Table B: Workforce schedule Logistic Department

Workforce Schedule Logistic Department

Planned workforce

# FTE / shift	Morning	Afternoon	Night
Palletizer 1	1	1	1
Palletizer 1	1	1	1
Second warehouse	1	1	
Landfill truck	1	1	1
Depalletizer	1	1	1
Combining area	3	3	
Pallet sorting	1		
Diverse	1	1	1
External transport	3 until 6	3 until 6	2
Total # FTE	13 until 16	12 until 15	7
Total # shifts per week	5	5	5

Activity for Production line

Activity / Production line	1	2	3	4	5	6	7	9	10
Palletizer 1			•	•	•	•			
Palletizer 1	•	•							
Second warehouse							•	•	•
Landfill truck	•	•	•	•	•	•	•	•	•
Depalletizer				•	•	•			
Combining area	•	•	•	•	•	•	•	•	•
Pallet sorting	•	•	•	•	•	•	•	•	•
Diverse	•	•	•	•	•	•	•	•	•
External transport	•	•	•	•		•	•		

D. Inventory capacity analysis

For the production planning algorithm we define the internal inventory levels, which define the inventory trigger point for external storage. We use the inventory statistics of the inventory storage location “Hal West” and “Oude Hal” to define the internal inventory levels for a production line. The soft drinks of production line 4 are stored at the inventory storage location “Hal West” and the soft drinks of production line 10 are stored at the inventory storage location “Oude Hal”. The Logistic department define a maximum inventory level of 18500 pallets for Hal West and a maximum inventory storage level of 1900 pallets for the Oude Hal. Figure 12 shows the total used inventory capacity of Hal West together with the inventory capacity of production line 4 in the same period. With the total number of externally stored pallets per period, we define when the used inventory capacity of the soft drinks of production line 4 triggers the Logistic department to store pallets externally. We set the internal inventory level for production lien 4 to 3500 pallets.

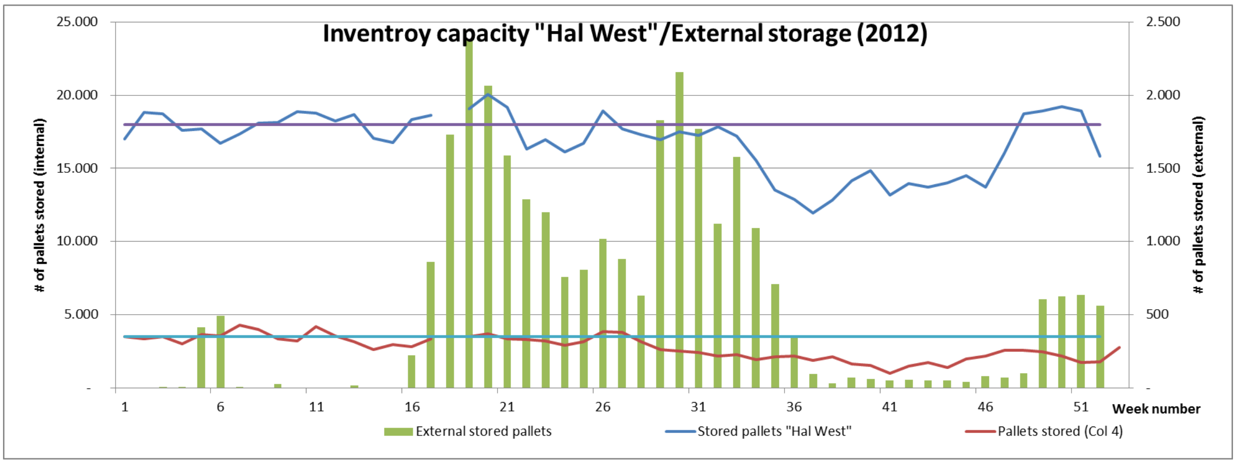

Figure B: Used inventory capacity “Hal West”

The storage capacity for the production lines 7, 9, and 10 proved to be enough for the soft drinks. When the number pallets exceed the capacity norm, the pallets are stored in “Hal West”. This does not directly lead to externally stored pallets. We assume that when there is not enough inventory capacity, the pallets are stored at the inventory location “Hal West” and trigger other soft drinks to store externally. For production line 10, we define the internal inventory level to 1330 pallets.

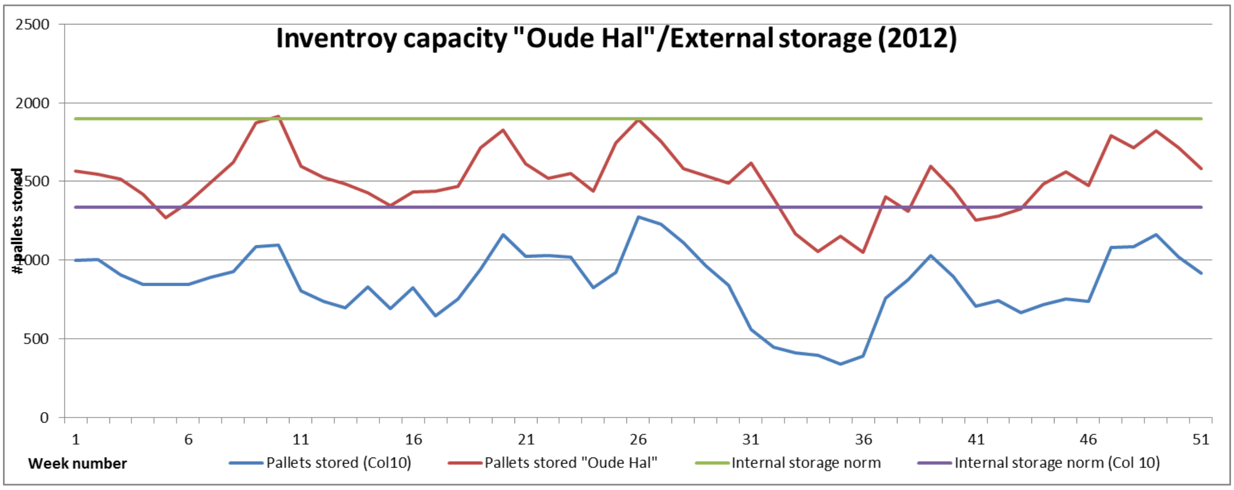

Figure C: Used inventory capacity “Oude Hal”

E. Cost analysis

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F. Total Production Management

Vrumona uses the methodology Total Productive Maintenance (TPM) to improve the availability of the machinery and continuous searching for improvement of all business processes within the company to increase the cost-effectiveness of the production. The TPM methodology builds on the concept of Lean manufacturing and especially focusses on the preventive maintenance of the machinery which "is about finding and applying a cost-effective ways to avoiding or overcome performance deterioration" and "improve asset performance, safety, soft drink quality, environmental health, process control and reducing the overall costs" (Ohunakin & Leramo, 2012). Companies that implement the TPM Methodology use the following eight pillars:

- Focused improvement
  - Continuous improving processes.
- Initial control
  - Minimize the lead-time of new soft drink or equipment introductions.
- Autonomous maintenance
  - "Maintain one's equipment by oneself"
- Planned maintenance
  - Focusses on increasing the availability of equipment.
- Quality maintenance
  - Maintenance for machines which are run on the zero-defects principle.
- Education and training
  - Developing the employees to work more efficient.
- Office TPM
  - Eliminate the losses of the work office (5S principle).
- Safety & Health and environment
  - Improvement of the work environment and impact of the soft drink/production to the environment.

The six biggest losses in production

- Breakdown of equipment
- Setup and adjustment
- Idle time and minor stoppages
- Reduction in production speed
- Quality and rework
- Start-up of the production

G. Initialization algorithms

The Adaptive Search (AS) algorithm and the Simulated Annealing (SA) algorithms need to be initialized. With several test for different parameters sets, we show how algorithms perform. This appendix shows how we define the parameter values for the algorithms.

Mixed Integer Linear program

The MILP needs a large amount of calculation time to solve the production planning problem. With 24 soft drinks and 9 product families, production line 4, the model is not able to find the optimal solution within four days calculation time. To initialize how much computation time this algorithm needs, we solve the model for the first week of 2012 with several termination times to define how much computation time the algorithm needs to retrieve a good quality solution. A computation time below 1 hour gives a poor quality solution. A computation time of two hours results in an almost equal solution compared to a solution with a computation time of 4 days.

The needed computation time for production line 10 to construct a good quality solution is lower than the needed computation time for the production line 4, because this production line has less soft drinks and soft drink families. A computation time of 30 minutes results an equal solution as a computation time of 4 days. We use a computation time of 1 hour for production line 10 and a computation time of 4 hours for production line 4, to construct good quality solutions for all planning problems.

Adaptive Search initialization

Our AS algorithm uses a bias parameter α and a summation weeks parameter θ to construct a production plan. We use a completely deterministic approach, high α, to define the best value for the demand summation parameter θ. To define the priorities, we experiment with a parameter value θ of 1 to 13. Figure F shows the results of these experiments for week 1 of 2012. Out of this figure we conclude that a θ of 7 results in lowest total costs.

------ figure is confidential ------

Figure F: Initialization parameter θ for AS

To initialize the parameter α, we experiment with an alpha between 0 and ∞. These experiments show that a higher parameter value results in the best quality solution. Therefore, our algorithm uses and a completely deterministic approach with a parameter value α near infinity.

Simulated Annealing initialization production plan

With the parameter value of the parameter θ for the AS algorithm, we define the best start temperature for our SA algorithm. To initialize this start temperature, we use the acceptance ratio-test. We experiment with several start temperatures and a fixed α of 0 and a fixed β of 1000 to construct Figure G. This figure shows that a start temperature of 5000, results in a acceptance ratio of 75%. Our algorithm works with several shift rules, which results in a small to large increases of the objective value. Therefore, use a start temperature 5000 that results in a 75% acceptance ratio. Figure H shows that a higher start temperature results in a poor quality solution.

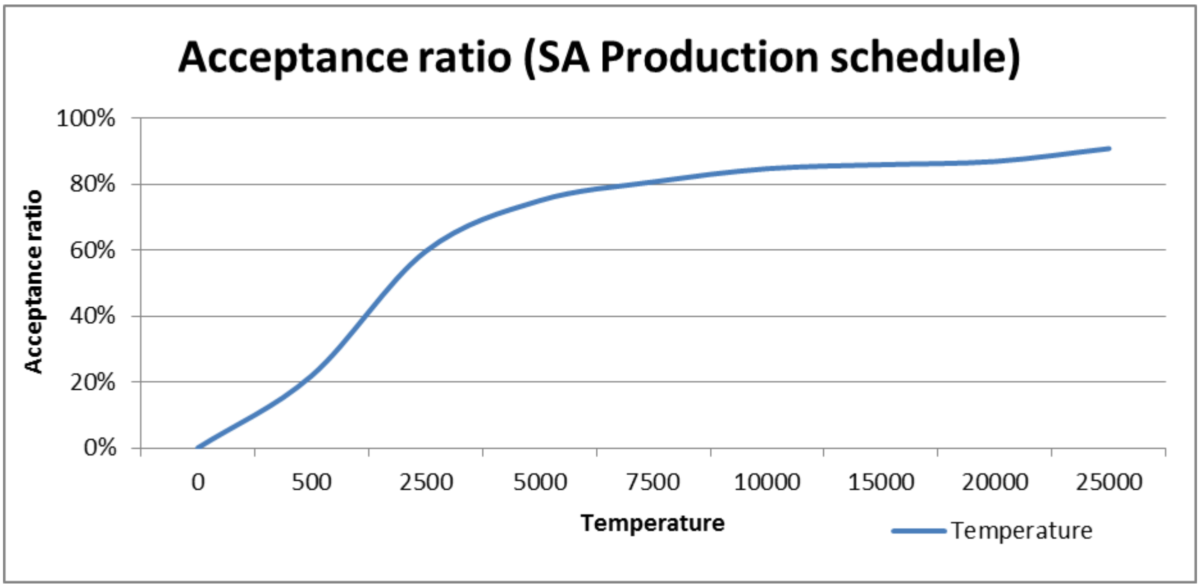

Figure G: Initialization start temperature (SA-production plan)

To define the objectives of the solutions for the different start temperatures, we define the parameter value α, and the parameter value β with several experiments. This resulted in a parameter value α of 0.999 and a parameter value β of 10. The termination temperature is set to 0.0005. Figure H shows the objective value of the solution of week 1 for different start temperatures. With the results of Figure G and Figure H, we conclude that a start temperature 5000 results in the best solution.

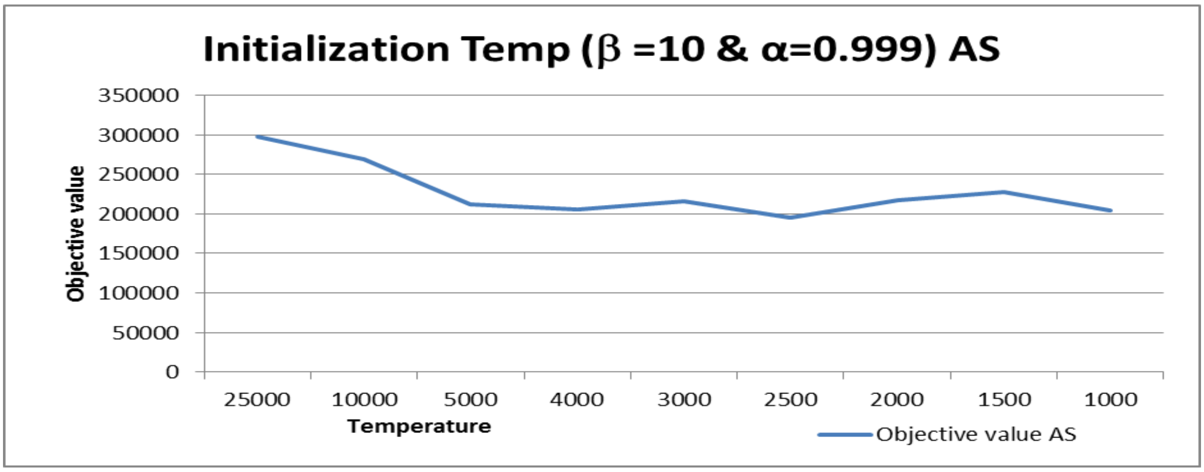

Figure H : Initialization start temperature with a fixed β and α

The AS algorithm selects soft drinks with an inventory level below the reorder level. Soft drinks of a product family with an inventory position below the can-order level are allowed to plan in a production week, when one of the soft drinks of this product family is planned. Function G.1 calculates the can-order level (number of weeks). The production leadtime is 1 week and we assume that the leadtime has a deviation of 1 week. Not all soft-drinks can be produced in the same week.

$$Canorder\ level\ = Leadtime + \frac{\phi(99{,}5\%)\sqrt{Leadtime * Stdev.demand^2 + \ Stdev.leadtime^2 * Mean.demand^2}}{Mean.demand} \qquad \text{(G.1)}$$

Simulated Annealing initialization production schedule

The Simulated Annealing algorithm for the production schedule uses the production plan as initial solution. To initialize the start temperature for this algorithm, we also use the acceptance ratio test. We experiment with several start temperatures and a fixed α of 0 and a fixed β of 1000 to construct Figure I. This figure shows that a start temperature of 150 results in a 95% acceptance ratio. This scheduling approach only uses the production sequence shift rule. Therefore, we start with a temperature of 150 to construct the production schedules. For this SA algorithm we use a parameter value α of 0.999 and a parameter value β of 10. The termination temperature is set to 0.05.

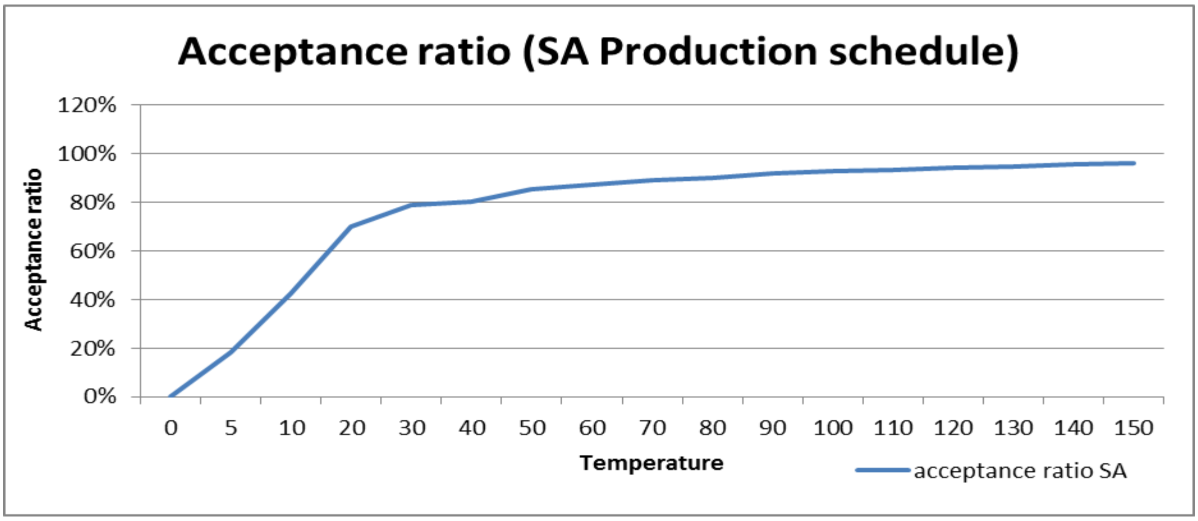

Figure I: Initialization start temperature (AS-production schedule)

H. Production planning results

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I. Validation of the solution

This section assesses the research on the four validity measures of Cook and Campbell (1979). The four validity measures are: internal validity, external validity, construct validity, and statistic conclusion validity. The validation of performance measurement data shows whether the constructed production plans result in the reliable outcome (Scandura & Williams, 2000).

Internal validity

The internal validity assesses whether the performance measures really measures the performance of a planning approach. To assess the planning approaches on the cost performance measure, the algorithms of the planning approaches "MILP/SA" and "AS/SA" calculate the total costs over the 26 weeks planning period. These costs are validated with a second calculation of the total costs for the constructed production plans. In addition, we cannot compare the costs for the production plans of the planning approaches with the actual costs, because the production planner modifies the production plan to fulfil the customer demand.

An extensive cost analysis defines the susceptible production costs and inventory costs. This cost analysis gatherers cost information from the operational, tactical, and strategic level of the company. By interviews several employees of the Production department, Sales department, and the Logistic department the costs are validated.The outcomes of the planning approaches on the other performance measure are also validated by interviewing the employees of the Supply Chain Planning department and Packaging department.

External validity

The external validity assesses the applicability of the planning approaches to other production lines. This research assesses two production lines with different demand characteristics and production capacity characteristics. With the outcomes of the planning approaches for both production lines we show that the planning approaches are applicable to other production lines. The planning approach "MILP/SA" accomplishes the largest estimate cost saving for both production lines. To apply the planning approaches to the other production lines the values on the input parameters for these production lines need to be defined.

Construct Validity

While defining the performance measures we used the Key Performance Indicators (KPI) defined by the company, the used performance measures, and the reviewed literature about production planning. This research uses six quantitative performance measures and four qualitative performance measures to assess the performance of the planning approaches. To validate the qualitative performance measures, we aligned our performance measures with the used performance measures in literature. The performance measures are validated by discussing the results with the employees of the related departments.

Statistic conclusion validity

The statistic conclusion validity compares the outcome of the planning approaches to assess the ability to draw a conclusion out of this statistical evidence. We developed a scheduling algorithm to compare the production plans of the three addressed planning approaches with the production plans constructed with the currently used planning approach. This results in an equal comparison of the production planning approaches, because this scheduling algorithm uses the natural sequence to optimize the production sequences within the weeks.