Eindhoven University of Technology

MASTER

Single machine multi-item hybrid MTO/MTS production system with setups and seasonal demand

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Eindhoven, June 2009

Single machine multi-item hybrid MTO/MTS production system with setups and seasonal demand

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in partial fulfillment of the requirements for the degree of

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in Operations Management and Logistics

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/ Master's Thesis

Production planning for a single multi-item hybrid MTO/MTS production system with setups and seasonal demand

Weert, R.J.L. de

Where innovation starts

Master's Thesis

Production planning for a single multi-item hybrid MTO/MTS production system with setups and seasonal demand

Written by:

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In partial fulfillment of the requirements for the degree of:

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I Abstract

This master's thesis project describes the development of a planning heuristic for a machine that produces concrete pavers. The demand is seasonal over a year. The machine has produced ca. 600 articles in the past two years. After an article has been produced the machine needs to be setup before it can produce another article. The planning heuristic takes both the seasonal pattern and setups into account. The heuristic is implemented in a tool.

II Preface

This master's thesis project marks the end of the master's degree program in Operations Management and Logistics that I have been pursuing at the Eindhoven University of Technology. The project has been carried out on behalf of Struyk Verwo Infra in Oosterhout. The last months where challenging but this project has been a rewarding experience from which I have learned a lot. I would like to take this opportunity to express my gratitude towards the people who have supported me during this project and master's degree.

I thank Simme Douwe Flapper for his guidance and support. His constructive criticism ensured the academic rigor of this project. His enthusiasm motivated me on many occasions. But foremost I would like to thank him for the engagement he displayed. Simme put a great deal of his time and knowledge at my disposal. It was never too much to ask. I thank Nico Dellaert for looking at the project from a broader perspective. He gave me the insight not to fret over what is not.

At Struyk Verwo Infra I thank Martin Moleveld he never lost his patience when I tried to explain my inventions. I also thank him for not being easily convinced and providing me with essential data. I thank Han for sharing his insights with me. I thank Peter and Vincent for providing me with data. Furthermore, I thank the entire team especially Anja, Maya, Maurits and Rini for the small talks and many laughs.

I thank my family and friends for showing their interest and support. Especially I thank my parents. Although my gratitude cannot be expressed by this gesture, I would like to thank them for supporting me, believing in me and just being there for me.

Rob de Weert

Eindhoven, June 2009

III Management Summary

Struyk Verwo Infra produces concrete pavers, tiles and curbs for predominantly the Dutch market. It has 11 manufacturing locations throughout the Netherlands. Each location has several machines. SVI experiences capacity problems.

The initial assignment was aimed at supporting the tactical planner in case capacity problems occur. A problem occurs if the demand on a certain machine exceeds the available capacity. These problems need to be solved quickly. In the current situation problems come unnoticed and are therefore solved ad-hoc. Also customer service e.g. the number of hours of lost sales is not measured. This means that we cannot quantify the capacity problem. Because we cannot quantify the problem we cannot determine the magnitude and relevance of the capacity problem. Second, we are not sure if the capacity problem can be avoided by improving the production planning method. This means that we could not continue with the initial assignment without the risk of solving a non-existent or possible avoidable problem.

We therefore did an internal exploration to investigate the production planning method in the current situation. We concluded demand to be seasonal over a year. However no anticipation stock levels have been set. We also concluded that the operational planners attempt to minimize setups by combining orders into one production run. Orders are combined by looking ahead in the order book. There is however no formal method that determines how far to look ahead.

Based on our findings in the internal exploration, we have decided to develop a tool that determines the optimal production quantities for a single machine. The production quantities need to minimize costs in the current and future months. The costs included are the holding costs and the lost sales penalty costs (in case of stock outs). We have decided to consider on a single machine because it makes no sense to optimize the control of multiple machines, on multiple locations if we do not know how to optimize the control of a single machine (on a single location). The tool can also be used to detect future capacity problems by doing a scenario analysis. Problems might be noticed further in advance than in the current situation. This gives the tactical planner time to find a structural solution instead of solving the problem ad-hoc.

The machine we focus on is the M1 located in Tiel. We decided to focus on this machine because 1) there are capacity problems on the M1 (according to the tactical planner) 2) the availability of detailed production data.

Analysis

To ensure that the tool is applicable to the situation at SVI we have analyzed: the objectives of SVI, the demand characteristics and the production characteristics.

After analyzing the objectives of SVI, we have defined two service measures that can be used to measure customer service in the feature. This can help SVI to quantify future capacity problems. It will also help to express the performance of the tool in another measure than costs.

After analyzing the demand characteristics, we concluded that an exact analysis of time varying demand is far **too complicated for routine use** in practice. We therefore decided to use a rolling horizon approach. It uses detailed demand information in the short term, and aggregate demand information in the long term. In the current month we need to have detailed demand information to decide what articles to produce. We need to have aggregate demand information to decide on the building of stock. The detailed demand information is based on 1) the order book 2) on a judgmental forecast made by Sales and Marketing on a limited set of (MTS) articles. The aggregate demand information is forecasted based on the actual aggregate demand in the same month of last year. The actual aggregate demand in this year is likely to deviate from the aggregate forecasted demand. The tactical planner can however evaluate the possible variations with the tool, using what-if scenarios. E.g. what if demand is 3% higher than last year?

After analyzing the production characteristics, we concluded that <<confidential>>% of the available capacity is spent on effective production. The setups consume 14% of the available capacity. Corrective maintenance and other delays add up to <<confidential>>% of the available capacity. The operational planners can decide on the amount of setups. Because the **setups consume a considerable amount of time** we include setups in the tool.

Research Questions

Given the seasonal demand pattern we have searched the available literature to answer the three questions below:

1. When to start the building of stock?
2. Which articles to select for the build up?
3. How to divide the capacity if we cannot satisfy all demand?

Another criterion was that the key-features of the literature would include setups. To the best of our knowledge there are no scientific articles that answer these 3 questions and include setups. We decided to adopt the article of (Ketzenberg, Metters and Semple 2006) as a starting point. (Ketzenberg, Metters and Semple 2006) developed a marginal analysis heuristic that 1) answered the three questions 2) is an improvement compared to other heuristics and 3) shows no signs of deterioration in performance as the number of articles increases. The basic idea behind marginal analysis is that, it divides the capacity over equally lengthened step sizes e.g. a step size of 1 hour. The heuristic will then decide for which article it is most profitable to spend the next hour on. Hereafter the heuristic will decide for which article it is the most profitable to spend the second next hour on. The advantage of marginal analysis is that it considers the marginal costs, marginal profits and the demand distribution function of each individual article (Ketzenberg, Metters and Semple 2006). The disadvantage is that the heuristic (or any of the other heuristics) does not include setups. We therefore adapted the original heuristic by including setups. The adapter heuristic attempts to avoid setups and includes the setup times in capacity calculations. The setup adaptation, several other (minor) adaptations and the resulting heuristic are described in detail in this project.

Implementation of the Tool

Based on the detailed description of the adapted heuristic, we implemented it in Microsoft® Office Excel® 2003; the tool. The tool was subject to validation and verification: we did extreme value and sanity tests and concluded the heuristic and tool to be valid.

We did a scenario analysis to investigate the potential decrease in costs. We therefore attempted to resemble the current situation at SVI. We are however not sure of the actual situation at SVI. The results make it plausible (but not certain) that the costs can be decreased. We can only conclude this with certainty, if we would have done the scenario analysis with the actual input data the operational planners have.

Although the potential of the tool remains unknown for know, we recommend the operational planner to use the tool. Compared to the current situation the tool uses a formal method to arrive at the optimal production quantities in each month. The tool however has limits e.g. it does not consider re-allocation or overtime. The quantities of the tool are a first start. They have to be **interpreted**. The operational planner does this based on his experience and common sense. In the end it is the operational planner that decides on the production quantities and not the tool. The final production quantities can be based on the production quantities proposed by the tool.

The use of the tool at the operational level might avoid certain problems. Other problems (e.g. caused by structural higher demand) cannot be avoided by the use of the tool. We therefore recommend the tactical planner to use the tool for scenario analysis. The tool might help to detect problems further in advance than in the current situation. This gives the tactical planner time to find a structural solution instead of solving the problem ad-hoc. Note that also the outputs of scenario analysis should be **interpreted** critically by the user. E.g. the holding costs, the penalty costs, the hours lost sales are expected values, and not the final values. Before the values become final, the tactical planner and operational planner have many **options to intervene**.

IV Table of Contents

1 Struyk Verwo Infra 1
  1.1 History 1
  1.2 The Present 1
  1.3 Future 3
2 Problem Definition 5
  2.1 Initial Assignment 5
  2.2 Internal Exploration 5
  2.3 Final Project Definition 8
  2.4 Research Approach 10
3 Objectives 11
  3.1 Objectives 11
  3.2 Customer Service Objectives 12
4 Demand Forecast 15
  4.1 Demand Forecasting Framework 15
  4.2 Demand Forecasting Process 15
  4.3 Data preparation 16
  4.4 Forecast 17
  4.5 Demand Forecast Control 17
  4.6 Conclusion 17
5 Capacity Usage 18
  5.1 Available Production Capacity 18
  5.2 Conclusions 20
6 Theoretical Basis 21
  6.1 Capacity Constraint 21
  6.2 Literature Review 22
  6.3 Basic Idea KMS 23
  6.4 Assumptions KMS & Adaptations 24
  6.5 Conclusion 26
7 Model & Heuristic 27
  7.1 Mathematical Description 27
  7.2 Marginal Analysis Heuristic 29
  7.3 Procedure Allocate 31
  7.4 Procedure Anticipate 33
  7.5 Conclusion 36
8 Software Implementation 37
  8.1 Software Selection 37
  8.2 Implementation in Excel 37
  8.3 Summary 37
9 Validation & Verification 38
  9.1 Modeling Process 38

9.2 Data Validity ... 38

9.3 Computerized Model Verification ... 38

9.4 Operational and Model Validity ... 38

9.5 Summary ... 41

10 Scenario Analysis ... 42

10.1 Framework ... 42

10.2 Insights ... 45

11 Implementation at SVI ... 50

11.1 Tactical Planner ... 50

11.2 Operational Planner ... 50

12 Conclusion & Recommendations ... 51

12.1 Project Deliverables ... 51

12.2 Conclusion ... 51

12.3 Recommendations ... 52

13 Scientific Reflection ... 53

13.1 Contribution to Literature ... 53

13.2 Future Research ... 53

14 References ... 54

15 Reading Guide ... 55

15.1 Tables ... 55

15.2 Figures ... 55

15.3 Abbreviations ... 56

15.4 Model Variables ... 56

15.5 Definitions ... 58

16 Table of Appendices ... 59

V Introduction

The aim of this introduction is to describe to structure of this report. The report follows the problem solving cycle or regulative cycle as developed by (Strien 1975) and described by (Aken, Berends and Bij 2004). The regulative circle is depicted in Figure V-1.

In all parts, literature is used to ground this report in the already available academic literature. A reference list can be found in **Chapter 14**. Throughout the report tables, figures, model variables, abbreviations and definitions are used. They are listed in **Chapter 15**. This should increase the readability of the report. To further increase the readability of the report, certain elements are excluded from the main text. They can be found in the appendices at the end. The table of appendices is presented in **Chapter 16**. Because **Chapter 7** makes use of many mathematical equations, this chapter may be difficult to read.

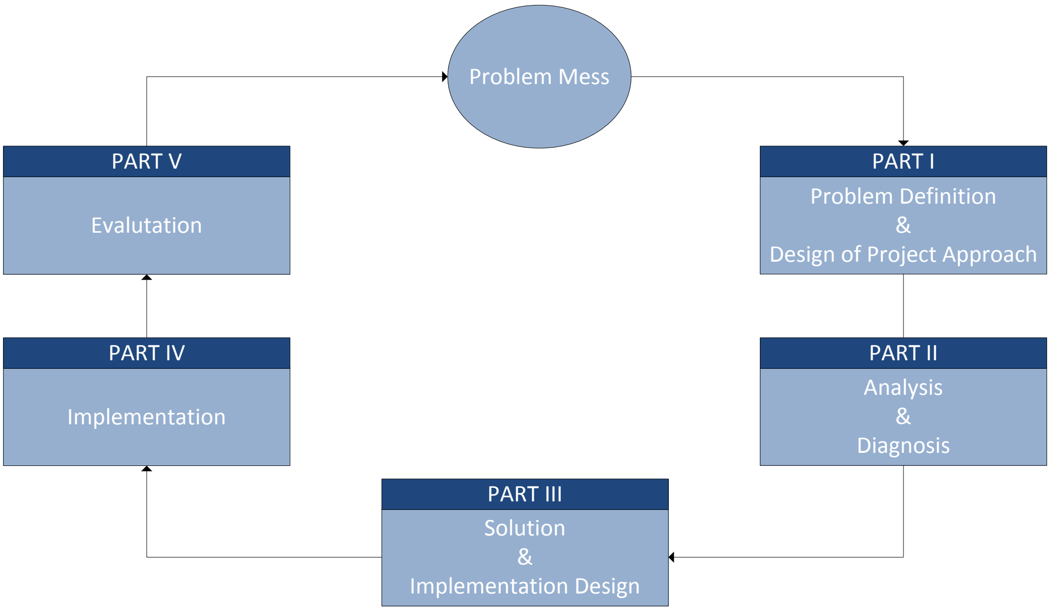

Figure V-1 **"Regulative Circle"**

PART I

Chapter 1 will get the reader acquainted with Struyk Verwo Infra. It is an introduction to the company and its business. After the introduction to SVI we introduce the problem in **Chapter 2**. Next, we will define the deliverables and determine the scope.

PART II

In chapters 3, 4 and 5 we will analyze the situation at SVI. In **Chapter 3** we have defined customer service objectives they will help to measure the performance at SVI. In **Chapter 4** we analyzed the demand characteristics. The capacity usage in the current situation and machine characteristics are described in **Chapter 5**. In **Chapter 6** we will describe based on literature research and the key features distilled in the aforementioned chapters a planning concept. Next, the applicability of the concept is discussed. We come to the conclusion that several adaptations need to be made.

PART III

In **Chapter 7** we present a dynamic programming model. Because the model cannot be solved within a reasonable amount of time we have developed a heuristic.

PART I

In **Chapter 8** the heuristic is implemented in a tool. The tool is subject to validation and verification in **Chapter 9**. In **Chapter 10** we consider several scenarios to investigate the performance compare to the current situation. In **Chapter 11** we discuss how and by whom the tool should be used at SVI.

PART V

In **Chapter 12** we will evaluate the project from a practical perspective and in **Chapter 12** from a scientific perspective.

1 Struyk Verwo Infra

This chapter introduces Struyk Verwo Infra. The purpose is to get acquainted with the company and its origins. In the next chapters certain factors can be traced back to the history. Current decisions can be affected by the company strategy. In the first section we present the history of SVI. In the second section the present company, the supply chain and market. The third section will give a glance at the future of SVI as it describes the strategy.

1.1 History

A. Struyk & Co. was founded in 1919 by A. Struyk in Oosterhout. It soon produced concrete tiles and besides natural stones it also started trading in building materials. In the financially difficult run-up to World War II the company managed to survive and even installed it first mechanized tile press.

After World War II the reconstruction of cities and factories started and this enabled the company to expand rapidly. In 1957 the company, then named N.V. A. Struyk & Co, opened a second production site in Oosterhout. After several acquisitions the concrete division would become one of the greatest concrete paver producers of the Netherlands. Besides pavers this division also produced concrete drainage and sewer products. The two other divisions, the building material trade and natural stone trade, would also continue to grow.

In the 1970's the company started a hardware store chain as a new division. In the 1980's declining profit margins in the natural stone trade forced the company to focus on the other divisions. In the mid-eighties due to fierce competition in the building material sector Struyk decided to sell its hardware stores and building materials trade division. Only the concrete division remained with pavement products and drainage and sewer products.

In the 1990's the company continuous to grow by acquisitions. In 1992 the descendents of founder A. Struyk decided to sell to company to CRH. CRH, headquartered in Ireland, is an international building materials group. After the acquisition CRH merged Struyk with Verwo Beton, which had been acquired earlier, into Struyk Verwo Groep. After the merger the Struyk Verwo Groep consisted of 4 divisions; Struyk Verwo Infra with concrete paving products, Struyk Verwo Aqua with concrete drainage and sewer products, Zoontjes with roof tiles and Wernink with industrial floor plates. The Struyk Verwo Groep became part of CRH Infrastructural Products Benelux (CRH-IPB) a Benelux branch of CRH. After the merger and restructuring CRH took over more competitors and added them to the Struyk Verwo Groep.

1.2 The Present

1.2.1 CRH-IBP

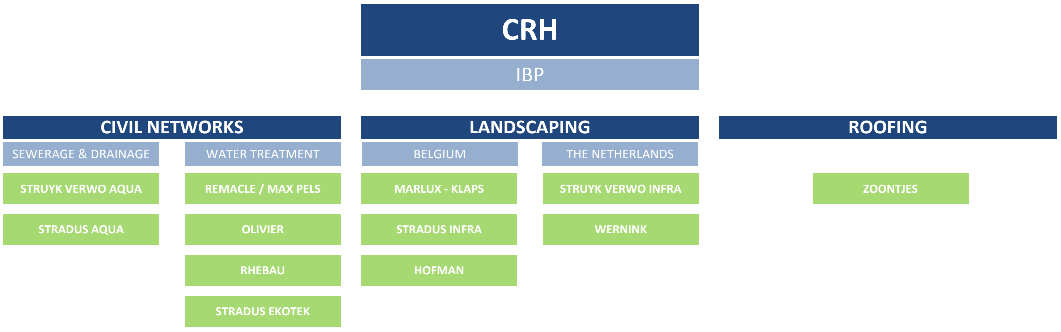

Figure 1.2-1 "**Group Structure**"

Today the former divisions of Struyk Verwo Group are now autonomous companies of CRP-IPB and as a result Struyk Verwo Groep does not longer exist as a separate entity. In total CRH-IPB now consists of a group of several autonomous companies divided over 3 product combinations. The company structure of CRH-IPB is depicted in Figure 1.2-1. In 2008 CRH-IPB employed approximately 1.550 employees at 31 locations. In 2008 with 20.000 million euro of sales, CRH employed approximately 92.000 people at over 3.500 locations.

1.2.2 SVI

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1.2.3 Supply Chain

In this section the production process and the supply chain are briefly described see also Figure 1.2-2. The main raw materials; cement, gravel and sand are delivered by ship or truck and stored at the production site on huge piles; Raw Material Inventory (RMI) in Figure 1.2-2. Concrete is produced by mixing the cement, gravel, water and sand. One location typically has only one mixing installation, supplying all machines. Chemical admixtures can further enhance the concrete characteristics. Each product has it owns concrete recipe which is created by varying the proportions of cement, gravel, water and sand. After the recipe is mixed, the mixture is pressed in a mold. When the mixture has adopted the shape of the mold it is released. This newly formed product is still very soft and therefore cured. After this step the articles are packed and stored; Finished Goods Inventory (FGI) in Figure 1.2-2. The product is distributed by contract carriers but also occasionally picked up by the customer.

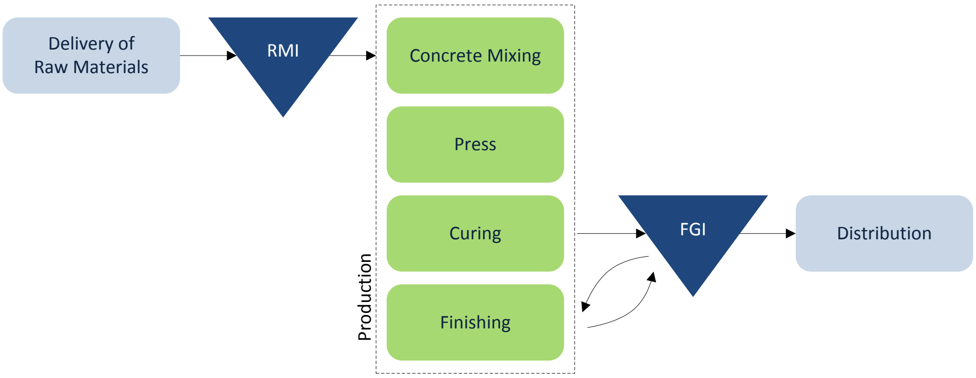

Figure 1.2-2 **"Supply Chain & Production Process"**

1.2.4 Products

With the production process as described above SVI is capable of producing a broad product range of ca. 19,000 articles. There are three main categories.

- **Curbs (Banden):** A curb is the edge where a raised pavement/sidewalk/footpath, road median, or road shoulder meets an unraised street or other roadway.
- **Pavers (Stenen):** An interlocking concrete paver is a multi-shaped, multi-colored piece of concrete commonly used in exterior hard scaping applications.
- **Tiles (Tegels):** Multi-colored piece of concrete used to cover sidewalks/foothpaths or squares.

1.2.5 Market

This section will describe the market. The source is an internal marketing document (Marketing Department 2008). It uses the competitive forces model of (M. Porter 1979). Along with the industry characterization this will explain the strategy in the next section.

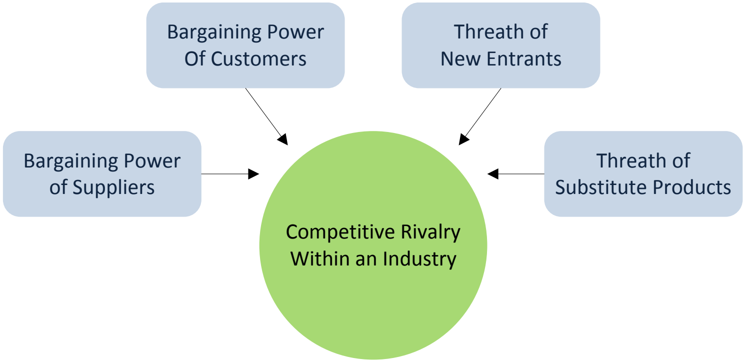

Figure 1.2-3 **"Competitive Forces Model"**

1.2.5.1 Competitive Rivalry within an Industry

The consolidation wave that resulted in SVI in the first part still continues at a slow rate. This is illustrated by recent acquisitions of SVI. The February 2008 survey from 'BEST', a sector journal, shows that SVI is overall market-leader in curbs, pavers, and tiles. Despite being a market leader SVI faces strong regional competition from several regional competitors. The journal also shows that the total market volume is not about to grow. This is expected to intensify the rivalry and to further deteriorate prices.

1.2.5.2 Bargaining Power of Suppliers

SVI is part of CRH and can therefore benefit from the purchasing agreements CRH has made. Despite this the bargaining power is medium (Marketing Department 2008).

1.2.5.3 Bargaining Power of Customers

The number of competitors and the homogenous product range among competitors make it easy for customers to switch; the concrete pavement market is thus a ‘buyer’s market’. Delivery records of 2007 show that products are either directly sold to contractors (60%) and municipalities (25%) and indirectly to retailers and competitors (15%). An increasing number of contractors operate (as a result of consolidations) nationwide. This has increased the buying power and professionalism of their procurement offices. Further municipalities are forced by the NMa (competition regulator) to call for tenders. This generates offerings from many competitors. Both developments and competitive rivalry give considerable bargaining power to the customers.

1.2.5.4 Threat of New Entrants

The investment intensity in the industry is high and the competitive rivalry fierce. These are market conditions unlikely to attract new entrants. New EU regulations make it possible for foreign competitors to enter the Dutch market. High transportation cost will however likely limited this effect to the borders.

1.2.5.5 Threat of Substitute Products

Depending on the market segment there are a number of substitute products available and it is easy for customers to switch between alternatives. Especially natural stones and asphalt are a threat. The easy switch is also an opportunity. A more dominant factor is the reuse of materials. Overall substitution is a medium threat.

1.3 Future

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1.3.1

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1.3.2

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1.3.3 Branding

As part of the differentiation strategy SVI's broad product assortment is regions and branded in 5 product families. Each family is supposed to match with the look and feel of the project in which they are used. Hence the articles are no longer marketed by product specifications but by a sales perspective that focuses on providing solutions. This should make it easier to approach decision makers downstream in the supply-chain with solutions instead of product specifications. Product families:

Street Style
Street Art
Street Works
Street Safe
Street Care

Figure 1.3-1 **"Product Families"**

Street Style: Luxury but affordable stones for prestigious projects. Natural stones of sister company Hofman are sold and distributed through the SVI network.
Street Art: Products in a wide variety in colors, appearances, size and shapes. Street Art gives each project an extra dimension without compromising functionality.
Street Works: Functional pavement products that are easy to process use and maintain and fit in every budget.
Street Safe: Innovative products to ensure a safe and efficient traffic flow (e.g. traffic calming products).
Street Care: Innovative products aimed at the environment they are in (e.g. products that handle traffic quietly).

2 Problem Definition

In the previous chapter we have introduced SVI. In this chapter we will introduce the initial assignment. Based on the internal exploration and the BWW-framework we will present the final assignment. The initial assignment is aimed at solving capacity problems ad-hoc. The final assignment is aimed at making optimal use of the available capacity thereby attempting to avoid problems. If the problem cannot be avoided we would like to signal the problem timely as this will allow SVI to react in a structured way as opposed to ad-hoc in the current situation. In the latter part of this assignment we will present the research approach for the next chapters.

2.1 Initial Assignment

At the start of each year a production plan is made. The outcome of the production plan is 1) an allocation of articles to a machine i.e. a list of articles to be produced on each machine and 2) the number of shifts on each machine. A capacity problem occurs if the production plan becomes infeasible i.e. the demand on certain machines exceeds the available capacity. There are no clear rules for choosing between solutions that overcome the capacity problem. In the current situation the problem comes unnoticed and solutions are picked on an ad-hoc basis. Because problems are solved ad-hoc SCM is uncertain if the solutions are optimal. This has lead to the following initial assignment:

“List the available solutions to overcome capacity problems.”

“Make a decision support model that enables the tactical planner to choose between these solutions when a capacity problem occurs.”

In the current situation the magnitude of the capacity problem e.g. the hours of capacity short, the penalty costs incurred and the amount of lost sales are not recorded. The customer service level is not formally defined or measured. This means that we cannot quantify the capacity problem. Because we cannot quantify the problem we cannot determine the magnitude and relevance of the capacity problem. Second, we are not sure if the capacity problem can be avoided by improving the production planning method. This means that we cannot continue with the initial assignment without the risk of solving a non-existent or possible avoidable problem. We have therefore conducted an internal exploration to examine which parts of the supply chain control structure can be improved.

2.2 Internal Exploration

To identify which parts of the control structure are (can be) the root cause of the perceived capacity problem we need to unravel the problem mess; a set of interacting cause and effect factors that hide the root cause(s). We want to remedy a (or the) root cause(s). To determine which factors are important and which factors are less import we will use the BWW-framework developed by (Bertrand, Wortmann and Wijngaard 1998).

2.2.1 Construction of the BWW - framework

The BWW-framework is used as a hierarchical supply chain control framework. An application of the BWW-framework for SVI is depicted in Figure 2.2-1. It shows the planning processes used to control the RMI, the production units and FGI.

The application of Figure 2.2-1 is based on interviews with the tactical planner, a project manager and the head of SCM. The project manager and head of SCM were asked because they are aware of the complete supply chain because they have already conducted several projects. The tactical planner was asked because she is responsible for the medium term plan made at the start of each year. Besides constructing the framework, the purpose of the interviews was to get familiar with the SCM department, get introduced to other employees at various positions within SVI and get familiar with the data sources. Based on the interviews we will focus on the control of the production units and FGI because none of the interviewed identified problems at RMI and distribution. The headings of the next sections can be traced back to Figure 2.2-1.

2.2.2 Medium Term Planning

The medium term planning is made once a year. As mentioned in the initial assignment during the year the planning turns out to be infeasible. The inputs of the medium term planning are –in the ideal situation– the customer service objectives, the demand forecast and the machine and product characteristics. In the remaining section we will first discuss the inputs. Second we will discuss the impact on the outputs: the capacity planning, the article allocation and the target stock levels.

2.2.2.1 Customer Service Objectives

The head of SCM stated in the interview that maximizing Return on Net Assets (RONA) is the higher order objective this is however not translated to customer service objectives. The customer service objectives are therefore absent.

2.2.2.2 Demand Forecast

Since demand is not known beforehand a yearly demand forecast is made. The forecast is structured over the main categories e.g. curbs +2%, pavers +3% and tiles -1%. There is no division within the main categories and the forecast is not structured over regions.

Not structuring within the main categories means that a plus in one article and an equal minus in another article of the same main category do not lead to a change in the demand forecast. If the articles are allocated to different machines (because of their technical features) it changes the machine loadings while the forecast has not changed.

Not structuring over region means that a plus in one region and an equal minus in another region cancel out. Sales however places an order at the nearest machine (provided that the article (or a nearly identical article) can be produced on multiple machines); this can lead to changed machine loadings while the forecast has not changed.

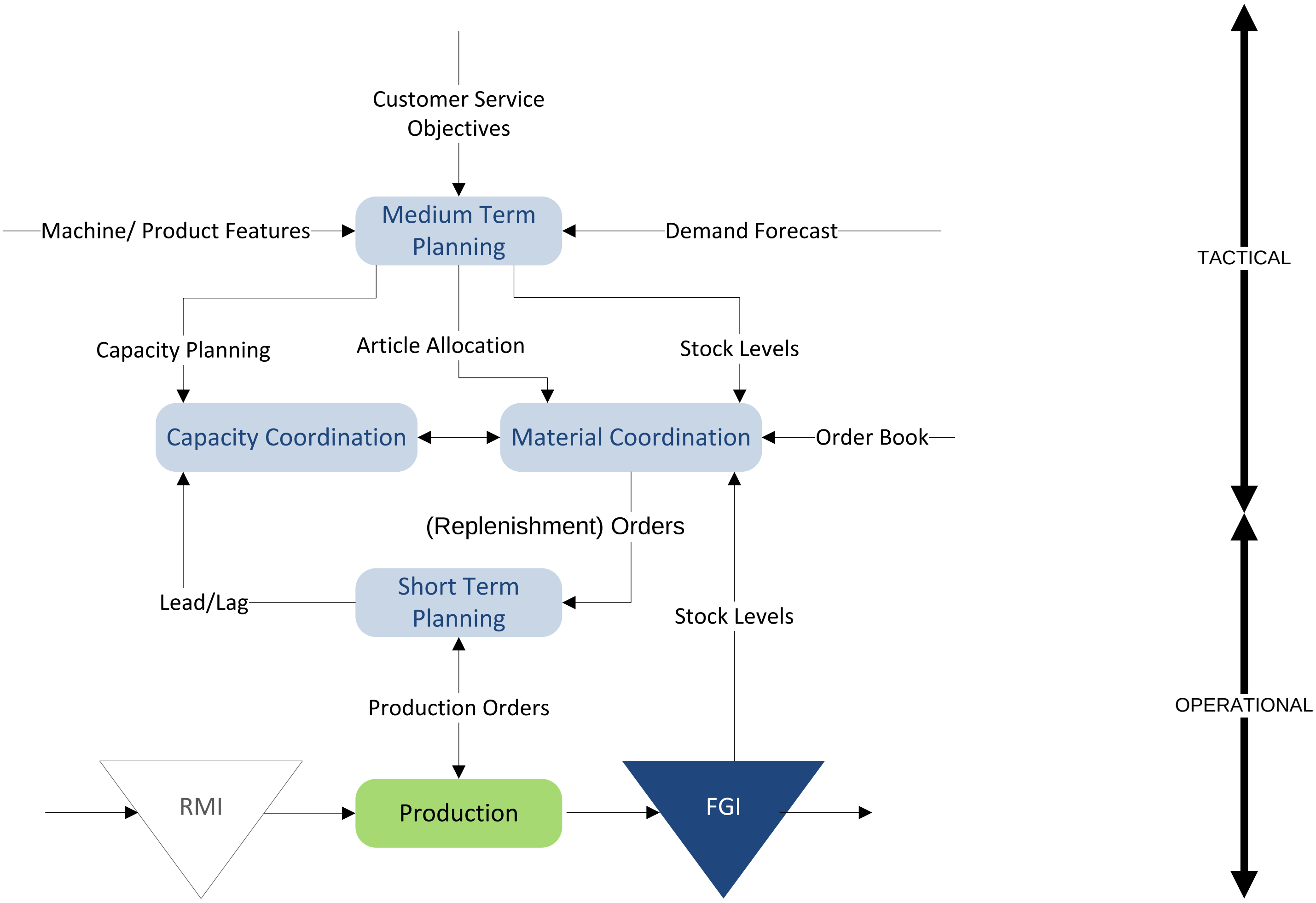

Customer Service Objectives
Machine/ Product Features
Medium Term Planning
Demand Forecast
Capacity Planning
Article Allocation
Stock Levels
Capacity Coordination
Material Coordination
Order Book
(Replenishment) Orders
Lead/Lag
Short Term Planning
Stock Levels
Production Orders
RMI
Production
FGI
TACTICAL
OPERATIONAL

Figure 2.2-1 **"BWW-framework"**

2.2.2.3 Input; Machine/ Product Features

The forecasted demand needs to be produced. To do this the forecasted demand for the articles is allocated to a machine. To allocate the forecasted demand to the available machines we need to know the article features and machine features.

Whether an article can be re-allocated to another machine depends on the technical features and the mix silo at the location of the machine. Recall that SVI is the product of several acquisitions and therefore both the machines and mixing processes differs from location to location. Because the machines differ the molds cannot be exchanged. New molds require an investment that needs to be accorded by F&A and after accordance it takes on average 8 weeks before the new mold is delivered. Because the mixing processes differ this can lead to color differences. A single customer that has had deliveries from multiple locations and uses these deliveries on a single project will detect the color variations. This puts limits on the allocation options especially for articles with non-standard colors (e.g. not grey or black) according to the project manager.

There is currently no matrix that lists the machines to which an article can be allocated. This matrix is not easily constructed because it requires expert knowledge to link the technical features and color of an article to the capabilities of a machine and the associated mixing process.

2.2.2.4 Output; Article Allocation

Because the matrix that links article features to machine features is missing and –because of the missing data– there is no method to allocate the expected demand. Consequently next year’s allocation is equal to this year’s allocation. In case last year’s allocation led to overutilization on some machines while other machines where underutilized some articles are than re-allocated. (Note that the utilization level similar to perceived capacity problem is not quantified.) The re-allocation is done based on experience**.**

2.2.2.5 Output; Stock levels

Articles at SVI are produced by either a Make-To-Stock (MTS) or a Make-To-Order (MTO) strategy. SVI aims to deliver MTS articles directly from stock. Because demand is uncertain SVI has set safety stock levels. Safety stock protects SVI against stock outs in case actual demand until the next production run turns out to be higher than expected. The level of protection depends on the service objectives.

The safety stock levels (and the length of a production run) are currently set arbitrarily depending on experience and based on qualitative relations. There is no insight in quantitative relations. The safety stock level setting is therefore likely to be flawed (Silver, Pyke and Peterson 1998). But this is not easy to conclude as customer service is not defined (or measured).

2.2.2.6 Output: Capacity Planning

The aim of capacity planning is to make sure that there is ‘enough’ capacity to fulfill expected demand. The article allocation and the capacity planning are not made independent. As part of the article allocation it is made sure that each machine operates at roughly equal levels of utilization. E.g. if expected paver demand is higher than last year and extra capacity is required first a shift is added to a machine that produces pavers. Second, articles from the other machines are re-allocated to machine with the extra shift to balance utilization levels.

Whether there is ‘enough’ capacity however also depends on the timing of demand. Based on the shipment data we have made Figure 2.2-2, it shows the monthly paver shipments for 2006 and -on the left- 2007 in ton kg.

The curbs and tiles shipments show a similar demand pattern in 2007 and 2006; they can be found in 0. Because the figures show roughly the same pattern we conclude that demand is seasonal over a year. This was confirmed in the interviews with the tactical planner and project manager. It makes sense because frozen ground and rainy weather make it impossible to lay pavers and this explains the peak periods surrounding the summer: June and October. The off peak period in the summer –August– is explained by a collective vacation in the building sector. Both SVI and its customers are closed.

The tactical planner stated that the available production capacity remains roughly level over a year. The available production time is depicted in Appendix C. This strategy is called ‘level’ (Silver, Pyke en Peterson 1998).

In case peak demand exceeds the regular production capacity, capacity needs to be stored in advance of the peak period. This is called anticipation stock. Anticipation stock levels are currently not set, hence they are zero. Note that with a level strategy and anticipation stock set to zero capacity problems do not need to surface during the off peak periods as demand is fulfilled at the targeted –informal- service objective. If the problems surface on short notice they need to be solved ad-hoc.

<<confidential>>

Figure 2.2-2 **“Paver Demand 2006 & 2007”**

2.2.3 Coordination of Capacity and Materials

The forecasted demand –as will any forecast– deviates from actual demand. This means that infeasibilities between demand and capacity can still occur despite the (optimal) planning method. The supply chain control should incorporate forecast errors as noted by (Silver, Pyke and Peterson 1998).

In the BWW-framework this is done by the coordination tasks between the medium term planning and short term planning. Infeasibilities in the medium term planning outcome due to e.g. increased demand are solved by reallocating orders to other machines (material coordination) or increasing capacity (capacity coordination). The coordination function is triggered by lower (higher) than expected stock levels or a lead (lag) in the lead-times as agreed upon. A lead (lag) is used to measure the time articles are finished ahead (behind) the agreed upon lead time. In the current situation stock levels are not set formally and lead (lag) is not defined or measured.

2.2.4 Short Term Planning

The short term planning is made every week by the production planner. He decides upon the schedule (article and quantities) to be produced every week.

The machines produce one article at a time and need to be setup before they can produce another article. The production planner attempts to minimize setups and maximize effective production time i.e. the time available for production after setups and other delays. He does this by manually assessing the order book and stock levels. The order book is a record in SAP that lists the quantities due for each article per day and customer. The production planner creates production orders by combining the quantities due for an article in the order book. There is no model that helps to decide how far to look ahead in the order book, the current method is based on experience. In the interview the tactical planner stated that the production planner in Oosterhout produced on average 10 - 14 weeks in advance of the due date in the order book. This statement is backed by a management report made by the stock manager see also **Error! Reference source not found.**. The report ndicates the stock level varies between 13 and 18 weeks of production (aggregated over all the production sites). An interview with the production planner in Tiel revealed that he combines further ahead in the off peak periods. In the peak periods he combines not so far ahead and gives priority to the articles that need to be finished according to the order book or pressure from Sales.

Contractors, SVI's main customers, examine tenders and work given out by municipalities and make a bid by estimating the amount of labor and articles needed to meet the specifications of the tender (Veeken and Wouters 2002). The bid is prepared by a cost engineer and the quantity of articles quoted depends on his assumptions. When a project has been acquired the contractor places an order for the materials needed and the order book at SVI gets filled.

According to (Veeken en Wouters 2002) the amount of articles and the amount of time needed as calculated by the cost engineers appears rather theoretical as the project foremen inspect the circumstances at the work site. This causes the order book to change (the articles, the article quantities and the timing). This means planners risk producing the wrong articles in the wrong quantities at the wrong time. This risk is higher as the expected delivery date is further away. Note that this is more of a problem for MTO articles because they are made especially for certain customers.

2.3 Final Project Definition

A clear understanding of the final project is needed to prevent differences in expectations at the end. A justification of the decision that led to the final assignment and an unambiguous assignment description and project deliverables will help to gain support within the organization.

2.3.1 Final Assignment

We have seen that (1) stock levels can be set as a part of the capacity planning in anticipation of peak periods. (2) Stock levels can also be set as protection against stock outs since demand and the time until the next production run are uncertain. In the current situation there is no formal method for building stock or setting safety stock levels.

We have also seen that operational planners attempt to minimize setups by looking ahead in the order book and combining the quantities due in a single production run. In the current situation there is no formal method that decides how far too look ahead in the order book.

In close cooperation with the project manager the following assignment has been defined:

"Develop a tool that determines the optimal production quantities for a single machine in order to minimize costs subject to the capacity constraint"

The costs included are the holding costs and penalty costs (in case of stock outs). The capacity constraint is the time available for production i.e. the time that can be used for effective production or setups. We decided to consider a single machine. SVI has multiple machines at multiple locations. It does however not make sense to optimize the control of multiple machines in multiple locations if we do not know how to optimize the control of a single machine (on a single location). Once we know how to optimally control a single machine we can start to optimize the control of two machines at a single location and hereafter multiple machines at a single location. In the end we can optimize multiple machines at multiple locations. Second, by optimizing the control of a single machine capacity problems might already be avoided.

2.3.2 Deliverables

In cooperation with the project manager responsible for this project the following project deliverables have been defined.

1. *Mathematical Model*
   Develop a mathematical model that determines the optimal production quantities for each article in the current period. The production quantity needs to high 'enough' to avoid stock outs in the present and future periods. The 'enough' strikes a balance between the holding and penalty costs. The inputs for the model are current stock levels, the holding and penalty costs for each article, the expected demand and the time available for production in the present and future periods. The model focuses on a single machine but should be applicable to machines with identical features.

2. *Tool*
   - *(a) Based on the mathematical model and the inputs (current stock levels, holding costs, penalty costs, expected demand and the time available for production) a tool needs to be developed that determines the optimal production quantities. The time available for production and the costs need to be adjustable because they can change over time.*
   - *(b) The tool should also be usable to detect and quantify future capacity problems (e.g. expected penalty costs, expected number of hours short) based on current stock levels, the time available for production until the future period and expected demand until the future period. This can help to trigger the coordination function.*

2.3.3 Justification

In the initial assignment it is stated that SCM wants to solve capacity problems not in the current ad-hoc way but wants a tool that helps to choose from a list of predefined solutions. The tool we will deliver attempts to 1) make optimal used use of the available capacity thereby if possible avoiding capacity problems 2) detect future capacity problems and help to trigger the coordination function. If the coordination function is triggered timely there is enough time to solve the problem in a structured way and not ad-hoc. If the coordination function is not triggered timely is has been made sure that the capacity is used optimally and we are able to quantify the problem.

2.3.4 Scope

We focus on a single machine; the M1 in Tiel. The mathematical model and tool, the deliverables of this project, should be applicable to other machines within SVI with identical features. We haven chose to focus on the M1 because 1) according to tactical planner SVI has and still does experience capacity problems on the M1 2) there is detailed production data available. Hierarchically the scope of this project is between the medium term planning and the short term planning. The medium term planning is made once a year and the short term planning once a week. The tool will therefore use time periods of one month. This is short enough to notice the seasonal pattern and means that the tool can be used to detect future capacity problems. It is also long enough to not overly interfere with the weekly planning and scheduling of production. Second, in the current situation the tactical planner discusses planned production and on-hand stock once a month with the operational planner. The tool can provide input to these meetings and this is another reason to use time periods of one month.

2.3.4.1 Out of scope; Lead (Lag) in Lead Times

The coordination function in the BWW-framework can e.g. also be triggered by a lead (lag) in lead time. The lead (lag) in lead times is not defined and not easily monitored on an aggregate level. We will therefore not include this in our assignment.

2.3.4.2 Out of scope; Article Allocation

An important part of material coordination function is the allocation of demand over the available machines. We decided to consider a single machine with a given allocation. To change the allocation we need extra input. This input -a matrix that lists the machines to which an article can be allocated- is not available. Constructing the matrix would consume considerable time and would need to be done by an expert on the technical product/ machine features. Therefore in agreement with the project manager it was decided to exclude the allocation of articles in this project and focus on a single machine with an existing allocation. Note that in practice the allocation options are bounded by mold availability on machines and the mixture process at the location of the machine. Second, the tactical planner can still manually re-allocate and change the list of articles that need to be produced on the single machine the tool considers.

2.3.4.3 Out of scope; Capacity

Determining the amount of capacity i.e. the number of shifts is out of scope, it is merely an input to our model and tool. This is in line with (Wild and Schneeweiss 1993). They categorize manpower decisions to the appropriate hierarchical level; strategic; tactical and operational. The number of shifts per site is categorized to the strategic level. This is line with the procedures at SVI; the tactical planner addresses capacity problems and asks for an increase (decrease) in the number of shifts. The decision is however made at a higher level.

Overtime is according to (Wild and Schneeweiss 1993) a decision to be made at the lower operational level. The tactical planner does have a coordination function in the use of overtime e.g. prevent that one plant uses overtime while another plant is at low utilization. The tactical planner does this by re-allocating articles. The allocation of articles is however out of scope.

At the tactical level remains according to (Wild and Schneeweiss 1993) variations in the monthly work time e.g. six working hours a day in February and nine in March. The tool works with a given number of hours available for production in each month it does not calculate the optimal number. The tactical planner can change the number of hours available for production in each month manually.

2.4 Research Approach

The report follows the regulative cycle as developed by (Strien 1975). The cycle has 5 parts. Part I the orientation and problem definition phases can be found in chapters 1 and 2.

Part II the analysis and diagnosis phase can be found in chapters 3, 4, 5 and 6. In the current situation service objectives are not defined, set or measured. We will therefore have to define them to evaluate our tool in another measure than costs and to detect capacity problems. It will also enable SVI to quantify future capacity problems. We will derive the service objectives from the higher order RONA objectives in chapter 3. In chapter 4 we will analyze the demand. In chapter 5 we will calculate the time available for production. With the problem features as key words we will review the academic literature in chapter 6. We will discuss the applicability of the literature found.

Part III can be found in chapter 7. Based on the literature and the key characteristics we will develop a mathematical model.

Part IV the implementation phase describes how the mathematical model is implemented in a tool. This can be found in chapter 8. The tool and model are subject to validation and verification in chapter 9. In chapter 10 we will do a scenario analysis to test the applicability of the tool and arrive at some insights. Based on the scenario analysis we will advise SVI by who and how the tool should be used. This can be found in chapter 11.

Part V the evaluation of this project can be found in chapters 12 and 13. In Chapter 12 we will evaluate the project from a practical perspective and in Chapter 13 from a scientific perspective.

3 Objectives

The purpose of this chapter is fourfold. We will first briefly elaborate on the higher order RONA objective and show they can be translated to subordinate objectives. Second we will show that various trade-offs need to be made between lower order objectives and those objectives need to be aligned between the departments. Third we will differentiate between a MTS and MTO strategy and give three reasons to produce an article following a MTS strategy. Fourth we will give a service measure for articles produced by both a MTS and MTO strategy and argue why it is not possible to measure them in the current situation.

3.1 Objectives

3.1.1 Higher Order Objectives

Clearly defined customer service objectives are missing. Instead the head of SCM stated that maximizing RONA is the higher order objective against which service objectives on the operational level are traded off. We will briefly elaborate on this. The formulae (3.1-1 / 3.1-4) are from (Berk and DeMarzo 2007), they show a relation between RONA, Earnings before Interest and Tax (EBIT) and Net Working Capital.

$$RONA = \frac{Net\ Income}{Fixed\ Assets + Net\ Working\ Capital} \tag{3.1}$$

$$(Unlevered)Net\ Income = EBIT \cdot (1 - Corporate\ \ Tax\ Rate) \tag{3.2}$$

$$EBIT = \ (Revenue - Costs - Depreciation) \tag{3.3}$$

$$Net\ Working\ Capital = (Current\ Assets - Current\ Liabilities) = (Cash + Inventory + Receivables - Payables) \tag{3.4}$$

The high order RONA objective does however not help to make decision at the lower levels. We will therefore translate the higher order RONA objectives to lower order objectives that can be used to evaluate day-to-day performance.

3.1.2 Subordinate Objectives

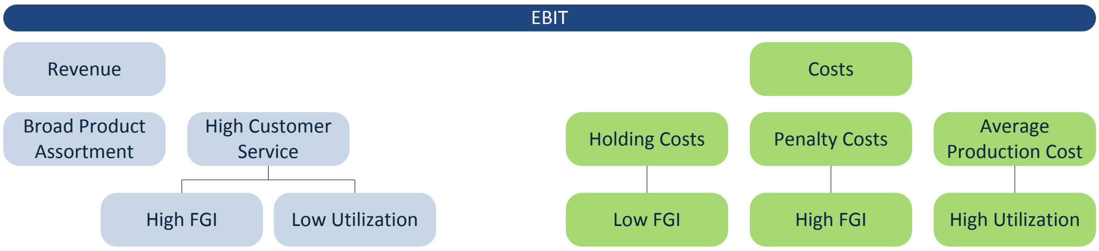


Figure 3.1-1 **"Hierarchical Objectives"**

The key EBIT factors (revenue and costs) and the relation with day-to-day performance factors are depicted in Figure 3.1-1. Only the factors within the scope of this project are depicted. We identify the following tradeoffs:

1. **Product Assortment:** A broad assortment gives the customers plenty of choice and he is likely to find what he needs. This increases revenues. A broader assortment leads to more setups unless the lot size is increased. The setups consume time and diminish the time available for effective production. Note that the number of setups can be kept stable or decreased by increasing production lot sizes at the cost of higher FGI.
2. **Utilization:** If the machine is idle it can be setup for production immediately after a customer order occurs. If the machine is still busy for another customer order, we have to wait. At high utilization levels changes are likely we have to wait for several other customers. The advantage of high utilization levels is that the same fixed costs e.g. overhead or machine leases can be divided over more articles and average total production costs are lower.
3. **FGI:** There is also FGI because customers are unwilling to wait for certain articles. To avoid that customers need to wait these articles have to be MTS. Low FGI will results in low holding costs, high FGI will result in low penalty costs.

3.1.3 Aligning Subordinate Objectives

Management is aware of the relations depicted in Figure 3.1-1 and they have set the following lower order objectives:

1. They give room to Sales and Marketing to continuously introduce new articles that accommodate customer preferences thereby **broadening the assortment**.
2. They reward production planners for high production efficiency i.e. high output, **high utilization**.

3. The tactical planner has been made responsible for keeping **FGI low**.

From the above we conclude that the objectives from Sales and Marketing, production planners and the tactical planner are not aligned. Although a common flaw (Kerr 1995) the wrong (overall) behavior might be rewarded. It should be mentioned that because of mutual pressure from all sides the negative effects of the reward system are somewhat relaxed.

To achieve the highest overall performance the objectives between Sales and Marketing, production planners and the tactical planner need to be aligned because they are interdependent (Mitchell and Silver 1990) and aimed at the overall objective (Kerr 1995). In the remainder of this chapter we will analyze which objectives should be attained by the operational planners and the tactical planner. The objectives of Sales and Marketing are out of scope.

3.2 Customer Service Objectives

We already mentioned the MTO and MTS production strategy is we will now give an explanation. Second we will give argument why an article should be produced by either one of the strategies. Third we will define fill rate and delivery reliability as services measures. The service measures can be used for both MTO and MTS articles.

3.2.1 CODP

The CODP is in (Bertrand, Wortmann and Wijngaard 1998) described as the point after which activities in the supply chain become customer driven instead of forecast driven. This means that MTO articles are only be produced when there are customer orders. The production of MTS articles does not depend on customer orders but depends on forecasted demand (possible based on customer orders).

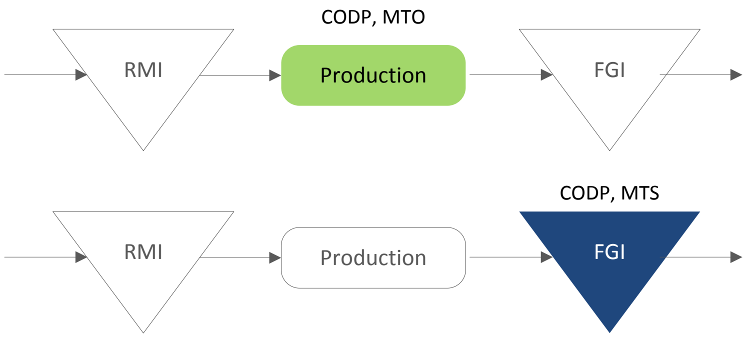


Figure 3.2-1 **“Customer Order Decoupling Point”**

The concrete mixture and/or mold for MTO articles differ from MTS articles. The production process is similar and takes place on the same machine. The two distinct CODP’s are depicted in Figure 3.2-1.

3.2.2 MTS vs. MTO

We will start by defining cycle time and lead time.

Cycle Time: The time between two consecutive production runs for the same article
Lead Time: The time between the placement of an order and the order being ready for distribution

Reasons to produce following a MTS strategy are:

1. **Lost Sales:** Customers are not willing to wait the cycle time for standardized articles. These articles are also offered by competitors and if they quote a shorter lead time (possibly zero lead time) sales are lost. To avoid lost sales for standardized articles they are MTS and hence the lead time is zero.
2. **Contracts:** In long-term contracts with a limited number of customers a lead time for certain articles is agreed upon that is shorter than the cycle time. To comply with the contract and to avoid penalty costs these articles are MTS.
3. **Setups:** Fast movers i.e. articles with high demand and low variability in demand can be MTS. These articles can be produced in large lot sizes because they are likely to be sold quickly. This approach will avoid setups at the cost of higher FGI.

3.2.2.1 MTO / MTS Threshold

SCM initiated a project to determine where the thresholds are between MTO and MTS. Note that only the latter MTS reason -setups- the threshold is a SCM decision, while the lost sales and contracts thresholds are Marketing and/or Sales decisions. It is however SCM responsibility to keep FGI low. Because of ongoing discussions between SCM, Marketing and Sales no decision has been taken yet. As a result the MTS-MTO classification has not changed in the past two years and the current classification is likely to be suboptimal.

3.2.3 Fill Rate

We will first define On-hand Stock, Backlog, Lost Sales and Net Stock before we define Fill Rate as a service measure.

On-hand Stock: Physical available stock; it can never be negative
Backlog: In case on-hand stock does not allow a customer order to be satisfied directly and the customer is willing to wait there is a backlog
Lost Sales: In case on-hand stock does not allow a customer order to be satisfied directly and the customer is unwilling to wait sales are lost
Net Stock: (On hand) – (Backlog); it can become negative
Fill Rate: the fraction of customer demand that is met without backorders or lost sales. The optimal fraction balances the holding costs, the penalty costs.

The definitions are taken from (Silver, Pyke and Peterson 1998). Note that we do not look into individual orders we only consider the result: total demand over all orders. We assume that a customer opts for a partial delivery in case the total order cannot be satisfied from on-hand stock. Other common definitions are **Cycle Service Level** and **Ready Rate**. The cycle service i.e. the fraction of cycles in which the on-hand stock is above zero. The ready rate i.e. the fraction of time the on-hand stock is above zero. We have chosen for fill rate because in the problem on hand the cycle time is not fixed and if on-hand stock drops to zero the product can be produced almost instantly. An overview of these and other service levels can be found in (Silver, Pyke and Peterson 1998).

3.2.3.1 Backlog vs. Lost Sales

We assume that customers are willing to wait for MTO articles. This will result in a backlog. Recall that we identified three reasons to produce article following a MTS strategy; 1) lost sales in case of standardized articles, 2) to comply with contracts and 3) setups. In case of standardized articles the fraction of demand that is not immediately met results in lost sales. We assume customers to step over to competitors. This assumption is valid unless (all) the competitors are also unable to deliver from on-hand stock. In case of contracts or setups reasons to produce following a MTS strategy the fraction of demand that is not immediately met results in a backlog.

3.2.4 Delivery Reliability

We will first define Quoted Lead Time and Due Date before we define Delivery Reliability.

Quoted Lead Time: The agreed upon time between the placement of an order and the order being ready for distribution. The quoted lead time results in a due date. In case an article is MTS the customer can request delivery at zero lead time.
Due Date: The date when an order is agreed to be ready for distribution
Delivery Reliability: the fraction of customer orders ready for distribution at the due date

The earliest lead time than can be quoted depends on the delivery reliability target and the level of utilization. As noted by (Dellaert 1988) to agree on to short lead times might increase demand in the short run, but might deteriorate delivery reliability and decrease demand in the long run. Quoting too long lead times to be on the safe side might also decrease demand despite scoring high on delivery reliability.

3.2.5 Complicating Factors at SVI

In this section we will show that the customer service in the current situation cannot be measured. We will first give an internal notation used for MTS and MTO articles and define inventory position.

At SVI MTS articles are denoted as A– Articles or B– Articles, MTO articles as B=0– Articles and C– Articles. There is no definition to categorize the articles.

Inventory Position: (On hand) – (Backlog) – (Reserved) + (Scheduled Production)

We will show why the ‘real’ inventory position is unknown and at SVI reduced to On-Hand stock:

1. There is no ‘real’ backlog, because there is no record with vain attempts to place delivery orders.
2. Forwarded MTS order lines or B=0 order lines already produced can be but are rarely reserved i.e. can be delivered to another order than it was produced for. C articles are always reserved.
3. Production is booked afterwards and not known in advance.

3.2.5.1 MTS, Forward Order

A and B articles are MTS and the customer can request delivery at zero lead time. At SVI however customers often do not need direct delivery and Sales books a forward order to be ready at a future due date.

3.2.5.2 Due Dates & Backlog

Although a due date is agreed upon for forwarded MTS orders and MTO orders, customers rarely request delivery at the due date. This means that the delivery reliability in our definition is likely to be lower than the external delivery reliability as perceived by the customers. However we do not know when customers request timely delivery because a Delivery Orders can only be placed if the Inventory Position is above zero. There is no record of vain attempts to place Delivery Orders. This means that we cannot calculate the fill rate. The record with vain attempts would denote the backlog or lost sales in the ideal situation.

3.2.5.3 Reserved

Forwarded MTS order lines and B=0 order lines are not reserved, this means that the recorded Inventory Position is higher than the 'real' inventory position. As a result stock can be 'stolen' for delivery on orders other than they were produced for. Especially for the B=0 articles this is problematic because they are only produced in case of MTO orders and if stock is 'stolen' production needs to be restarted.

4 Demand Forecast

The target of SVI is to fulfill demand at the targeted service objectives. We do not know actual demand until the customer orders; the CODP. Numerous decisions e.g. the procurement of raw materials, the article allocation and the capacity planning need to be made prior to the CODP. Note that this is the case for both MTO and MTS articles. The only decision that is deferred in the MTO case is the decision which article to produce e.g. raw materials and capacity needs to be available. Decisions taken prior to the CODP are based on a demand forecast.

4.1 Demand Forecasting Framework

We will use the demand forecasting framework depicted in Figure 4.1-1 based on (Kilger and Wagner 2008). We will elaborate on the phases in the next sections. The forecasted demand is an input for the medium term planning in the BWW framework as depicted in Figure 2.2-1.

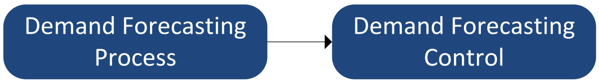


Figure 4.1-1 **"Demand Forecasting Framework"**

4.2 Demand Forecasting Process

In the ideal situation all steps in Figure 4.2-1 can be conducted. We will first describe the steps. Second we will argue the applicability of step 2 and present a rolling horizon approach to overcome the problems encountered in Step 2. Third we will argue what this means for Step 5 and 6.

4.2.1 Steps in the Demand Forecasting Process

In ***step 1*** the available data is prepared. The available data might need to be corrected e.g. shipment data needs to be corrected for stock outs. In **step 2** statistical methods -if applicable- are used to forecast demand based on the available data. In ***step 3*** Sales and Marketing are asked for information about specific events or changes e.g. new government legislation that will increase demand for certain articles. In ***step 4*** the results of steps 2 and 3 are combined. In **step 5** dependent demands are calculated. The independent demands for articles leads to dependent depend for e.g. capacity and raw materials. It is possible that there is a constraint on e.g. the available capacity. The feasibility of the consensus forecast than needs to be checked. In ***step 6*** the forecast is formally approved and released for use.

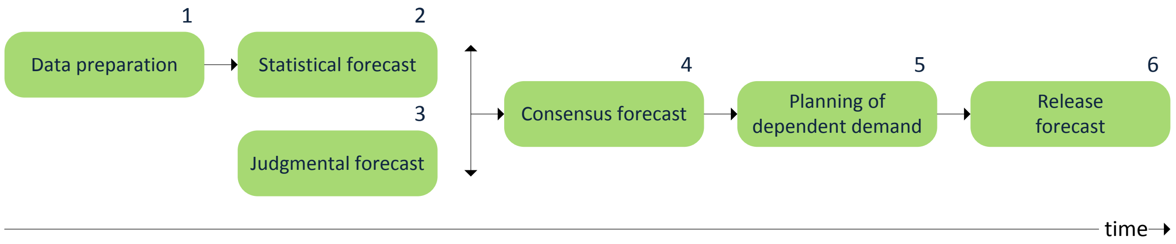


Figure 4.2-1 **"Demand Planning Process"**

4.2.2 Non-stationary demand: The Applicability of Step 2

Aggregate demand in the problem on-hand various over the seasonal cycle of a year. The demand for the individual articles depends on the project characteristics the customers from SVI are working at. The fact that the M1 has produced an article to be used in a single project in July 2007 may have little predictive value for July 2008. It all depends on the project characteristics the customers of SVI are working on. From this we conclude that the demand for articles is non-stationary.

(Silver, Pyke and Peterson 1998) argue that an exact analysis of time varying demand is far **too complicated for routine use** in practice. This means that we have to rely on 1) the order book and 2) the judgmental forecast made by Sales and Marketing. The disadvantage of the order book is that it is known only a limited amount of time in advance. Second, the MTS demand is not completely in the order book because the customer can request delivery for MTS articles at zero lead time. The disadvantage of the judgmental forecast is that we cannot expect Sales and Marketing to regularly update the expected demand for MTS articles not completely in the order book.

4.2.3 Planning of Dependent Demand: The Applicability of Step 5

The dependent demand we are interested in is the demand for machine capacity. The demand for machine capacity structured over the months allows us to make a capacity planning. If we would know the demand one year in advance the outcome of the planning would be e.g. built up 40 hours of inventory in January to be used in October. The tool should also be usable to detect future shortages. However the order book is only known a limited amount of time in advance. This means that we cannot plan as far ahead as we would like to; a full seasonal cycle.

To determine the expected shortage e.g. in October and the current month is January we have to forecast the demand for capacity in October. The expected shortage can then be calculated. The forecast can be based on the demand for capacity in October last year. This number can be revised up or downward based on again a judgmental forecast.

4.2.4 Rolling Horizon

From the last two sections we conclude that we have detailed demand information at the short term from the order book. We have aggregate demand information on the longer term based on the demand for capacity in each month in the last year. The information in the short term for MTS articles is not complete because not all MTS demand is in the order book. For the MTS demand not in the order book we will use a judgmental forecast. The aggregate demand information -the demand for capacity in each month- can deviate from last year. It can be updated by a judgmental forecast.

To use both the detailed and aggregate information we will use a rolling planning horizon of one year that is updated each month. We will use a planning horizon of one year because this includes a full seasonal cycle. The horizon is updated each month because the tool will also use time periods of one month and we want to use as much information as possible.

In the next section we will attempt to forecast the demand for capacity in each month based on the demand for capacity in the last year (s).

4.3 Data preparation

4.3.1 Data source

There are four data sources available at SVI; 1) the order book 2) shipments, 3) production data and 4) on-hand stock. We will only use the production data and on-hand stock because they are structured in a way that allows us to derive a demand pattern per machine.

4.3.1.1 Order Book

The order book at SVI is initial estimate of production quantities and due dates. The customer is not contractually obliged to take delivery (at any date) and can revise quantities upward and downwards at any point even after production. Production planners decide based on the order book and their own assessment what needs to be produced. This is fortunate because unnecessary production has been avoided in the past. The drawback is that it has resulted in an order book with orders which Sales does not expect to materialize but also failed to remove. We therefore have to conclude that this data source is not trustworthy.

SCM has initiated a joint project with Sales to improve the accurateness of the order book. Sales is supposed to request customers to update their sales orders in the week before planned production. This results in a go ahead, postponement or cancellation of the order. The objective is to avoid unnecessary production both in timing and quantities resulting in lower FGI.

4.3.1.2 Shipments

The scope of this project is limited to a single machine (on a single location). Shipments data is structured over locations, articles and time (date) and this results in over 200.000 yearly shipment records. Because some shipments are made through other sites and certain articles are produced on multiple machines and locations it is a lot of work to lead back shipments to a certain machine. Combined with the number of records this calls for a database structure to make a proper analysis. Developing this however would be beyond the scope of this project.

4.3.1.3 Production Data and On-hand Stock

Production is booked in SAP after actual production has happened. The production data is structured over machines, articles and time (date). On-hand stock in SAP is structured over locations and articles but not over time; there is no inventory history. The on-hand stock in SAP is therefore a snapshot. Fortunately the project manager has made snapshots of the on hand-stock at the start each month for the past two years, this gives us an inventory history. With this information we can derive the shipments structured over machines, articles and time. The shipments for each article of a machine can be estimated with the following formulae:

Shipments (units/article/month/location): On-hand stock (units/article/end of the previous month/location) + Production (units/ article/month/location) – On-hand stock (units/ article/end of the month/location)
In case an article is produced on multiple machines on the same location the on-hand stock can is multiplied by a machine multiple. We thereby assume that production of the article is equally divided over the machine(s) throughout the given period e.g. one year.

Machine Multiple (article): Production (units over a given period at a given machine/article) / Production (units in a given period over all machines on the location/article)

This gives the shipments per machine:
Shipments (units/article/month/machine): Machine Multiple (article) * Shipments (units/ article/month/location)

4.3.2 Synthesis

With the number of units shipped in each month we can calculate the number of machine hours needed in each month. This is a first estimate for the demand for capacity in each month. We will investigate the impact of setups in the next chapter.

The shipments per machine are not equal to the demand per machine. Recall that there is no record of lost sales or a backlog. This means that the 'real' demand remains unknown and the shipments only reflect the past delivery performance. Because the lost sales are unknown actual demand might have been higher. Because the backlog is unknown some customers might have requested delivery earlier than can be concluded from the shipment records. This means that the actual seasonal demand pattern is heavier.

4.4 Forecast

4.4.1 Consensus Forecast

The demand for capacity (from step 1) on a machine in a month can vary from the same month last year because of specific events that can be judged in advance, for example:

1. new legislation introduced by the government
2. general economic conditions
3. competitive forces
4. the introduction/ phasing out (because of allocations) of articles

Other reasons that cannot be judged in advance are for example:

5. weather conditions (that make pavement projects possible/not possible)
6. randomness in demand

In the forecasted demand for capacity we would like to incorporate the factors 1-6. Of course the precise impact can be hard to predict. Therefore we advocate the use of what-if scenarios to test the robustness of the plan. What happens if overall demand goes down by 3%? What happens if we would have a heavier seasonal demand pattern?

4.5 Demand Forecast Control

The forecasted demand will deviate from the actual demand. We are interested in the degree in which the forecasted demand deviates from the actual demand i.e. the forecast error. Modest deviations can be incorporated in the what-if scenarios. Beyond the what-if scenarios, the objectives as defined in chapter 3 might be at stake and the coordination function in the BWW- framework needs to be triggered. We would also like to know what caused the actual demand to deviate beyond the what-if scenarios. E.g. we underestimated the impact of new legislation. In the next forecast we would like to avoid the same error.

4.6 Conclusion

From this chapter we concluded that an exact analysis of time varying demand is far **too complicated for routine use** in practice. We therefore decided to use a rolling horizon approach. It uses detailed demand information in the short term, and aggregate demand information in the long term.

In the current month we need to have detailed demand information to decide what articles to produce. We need to have aggregate demand information to decide on the building of stock. The detailed demand information is based on 1) the order book 2) on a judgmental forecast made by Sales and Marketing on a limited set of (MTS) articles. The aggregate demand information is forecasted based on the actual aggregate demand in the same month of last year. The actual aggregate demand in this year is likely to deviate from the aggregate forecasted demand. The tactical planner can however evaluate the possible variations with the tool, using what-if scenarios.

5 Capacity Usage

In this chapter we will show that roughly <<confidential>>% of the available capacity in 2008 is spent on effective production or setups. The other <<confidential>>% is lost to various delays. We will also show that the production rate depends on the routing group and the time spent on setups can be diminished by sharing large setups. But first we will give some definition used.

Available Capacity: The time the machine can be used
Delays: The time that could have been used for production but is lost other than on setups e.g. corrective maintenance
Available time for Production: (Available Time) – (Delays)
Effective Production Time: (Available Time for Production) – (Setups)

5.1 Available Production Capacity

In this chapter we have used the production data from the M1 in Tiel, an excerpt can be found in Appendix E. The available capacity in hours and its usage are depicted in Figure 5.1-1. We have depicted the weekly levels to show that values are roughly equally divided over the weeks.

<<confidential>>

Figure 5.1-1 **"M1, Available Capacity & Usage"**

5.1.1 Effective Production

The number of units that can be produced depends on the production rate i.e. the number of hours needed for one unit. The production rate depends on the article characteristics. Articles with the same characteristics are grouped in a routing. A routing group is unique combination of a mold, mixture type and finish, see also Figure 5.1-2.

The mold is placed on a cardboard, filled with the mixture, the mixture is pressed and the mold is released when the mixture on the cardboard has adopted the shape of the mold. The production speed is derived from the number of articles that fit on a cardboard and the number of cardboards that can be processed per unit of time.

The mold can be filled with two distinct mixture types: one mixture 'door-en-door' or two mixture layers 'deklaag'. The bottom layer is a plain concrete mixture and the top layer is a colored mixture. Filling the mold with two mixtures consumes more time.

Afterwards the article's can receive a finish. A common finish is washing. The surface is roughed by removing sand particles with water pressure. Note there a numerous articles that receive no finish.

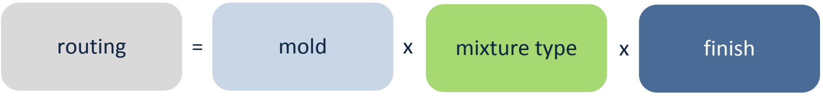


Figure 5.1-2 **"Routing Group"**

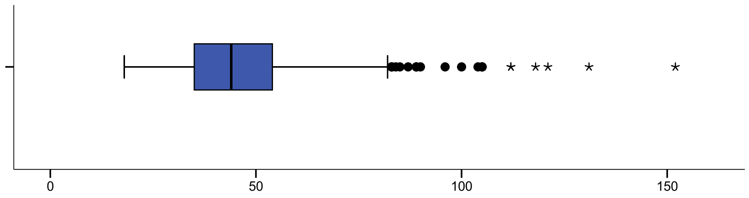
After the optional finish the article is cured for two days. The curing time is however not included in the production rate. We also do not consider the curing time as part of the lead time. We assume this is safe because the curing time is small compared to the quoted lead time: ca. 8 weeks as stated by the project leader.

5.1.2 Setups

We can identify setups within a mold -color changes- and setups between molds -mold changes-. We will refer to mold changes as large setups and color changes as small setups. We have made box plots for both the small and large setups. Although a limited number of outlier elevates the average we will continue with the average values in the next chapters.

5.1.2.1 Large Setup Time

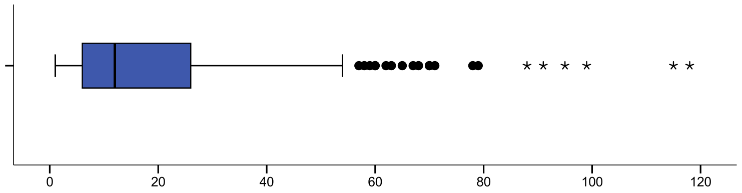
A box plot is a convenient way of graphically depicting the length of each setup (here in minutes). The bold line within the box (Figure 5.1-3 and Figure 5.1-4) is the median. Halve of the setups are shorter than the median, halve of them are longer. The left bound of the box is the 1st quartile, 25% of the setups is shorter. The right bound is the 3rd quartile, 25% of the setups is longer. The dots (at the right) represent outliers, the asterisks extreme outliers. Both box plot show that there are a few values (the outliers) that elevate the median to the mean. The median is less influenced by the outliers.



Median	44
Average	46,85
Count	433

Figure 5.1-3 **“M1, Box plot Large Setups”**

5.1.2.2 Small Setup Time



Median	12
Average	18,59
Count	599

Figure 5.1-4 **“M1, Box plot Small Setups”**

Note that large setups consume more time than small setups. This gives an incentive to minimize the number of large setups by combining articles that share a large setup.

5.1.3 Corrective Maintenance

Each delay in the production data file has a description. We investigated whether corrective maintenance entries are related to setups. We grouped the corrective maintenance entries into 20 categories. After ranking the groups after total delay time (largest – smallest) we made Figure 5.1-5. It shows the time lost as percentage of the available capacity. We did not depict the smallest values separate but grouped them into ‘other’. An interview with the production planner in Tiel revealed that the mold can get damaged after a setup. We however assume there is no relation between corrective maintenance and setups because the small value (0,99%) does not justify an thorough investigation.

<<confidential>>

Figure 5.1-5 **“Corrective Maintenance”**

5.1.4 Various Delays

The other delays (other than corrective maintenance) are depicted in Figure 5.1-6. It shows the time lost as percentage of the available capacity. The values add up to <<confidential>>% of the available capacity. We have decided to not investigate the cause of the delays because that would not fit within the duration of this project.

<<confidential>>

Figure 5.1-6 **“Various Delays”**

5.2 Conclusions

In this chapter we have seen that the effective production time is <<confidential>>% of the available capacity. The setups consume <<confidential>>% of the available capacity. The operational planners can decide on the amount of setups. Because the setups consume a considerable amount of time we will have to include setups in our model. This means that the time that can be used by the tool in the next chapters is the time available for production i.e. the total time that is spent on effective production and setups in the current situation. We have decided to not incorporate corrective maintenance and the various delays in the model.

Corrective maintenance consumes <<confidential>>% of the available capacity. After categorizing the corrective maintenance entries into 20 groups none of the groups was accountable in a significant matter. The corrective maintenance entries could also not be traced back to setups (in a significant manner).

The various delays account for <<confidential>>% of the available capacity. We have decided to not investigate the cause of these delays e.g. whether they are avoidable because that would not fit within the duration of this project.

6 Theoretical Basis

We have described demand and capacity in Chapters 4 and 5. The aim of this chapter is to link demand and capacity together by presenting the theoretical basis for a mathematical model. The mathematical model is presented in the next chapter. We will first argue that the optimal inventory level balances inventory holding costs and penalty costs in case of stock outs. Because of the production capacity is constrained the optimal levels may be not within reach in the peak periods. If the optimal levels are not within reach in the peak periods we can start producing beyond immediate needs by building up anticipation stock in the off-peak periods that proceed the peak periods. This leaves us with three basic questions 1) when to start the built up of anticipation stock and 2) which articles to use for the building of stock and 3) how to divide the capacity if we cannot satisfy all demand. In the second section we will search the available literature for an answer to those questions. In the third part of this chapter we will explain the basic idea of (Ketzenberg, Metters and Semple 2006). In the fourth part we argue whether the assumptions (Ketzenberg, Metters and Semple 2006) make hold for the problem at SVI and present adaptations if necessary.

6.1 Capacity Constraint

Each time period we have to decide how much to produce of each article, producing too few articles will result in penalty costs producing too much will result in holding costs. The optimal level in a single period with stationary demand and without capacity constraint can be found by using a 'newsboy' equation (Silver, Pyke and Peterson 1998). The optimal level balances inventory holding costs and penalty costs in case of stock outs.

The available capacity in each period is constrained. This means that we might be unable to reach the optimal inventory level in each period, despite having 'enough' capacity over a full seasonal cycle. To avoid penalty costs in the peak periods we will therefore need to build up stock in anticipation of the peak period. We will first give a general introduction to this concept. Second we will argue when to start the built up of stock and third we will briefly elaborate on the division of anticipation stock among the articles.

6.1.1 Level Strategy

A strategy where the production capacity remains constant e.g. at 80 hours per week and the seasonal fluctuations in demand are absorbed by inventory is in the literature known as 'level' strategy. The inventory is built up in the off-peak periods. This strategy differs from a 'chase' strategy that absorbs the seasonal fluctuations by varying the production capacity e.g. 40 hours per week in the off-peak periods and 100 hours per week in the peak periods. Most firms will pursue a mixture of both level and chase strategies (Silver, Pyke and Peterson 1998). In its pure form the level strategy is characterized by holding costs in the off-peak periods vs. penalty during peak periods. The chase strategy by hiring and firing costs vs. penalty costs during the peak periods.

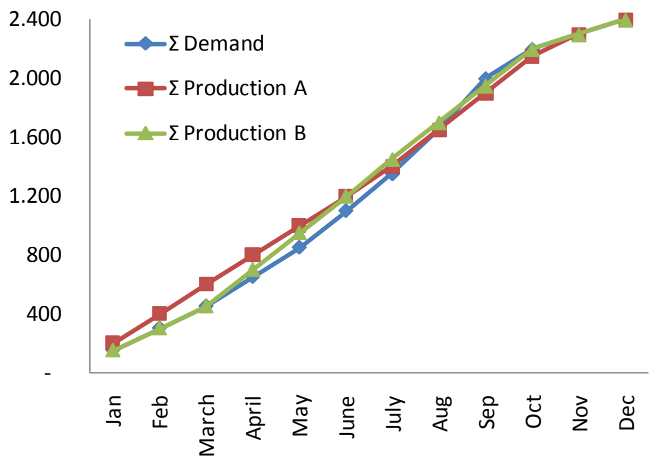
The capacity at SVI is constrained by the number of machines and the number of machine hours rather than by the number of people. E.g. it takes three employees to operate a machine at maximum speed. If three employees are already employed, hiring - and later on firing- an extra employees only makes sense if the number of machine hours can be increased. This can be done by adding a shift or working overtime. Employment contracts permit an extra shift only for a whole year and not as a temporary solution in the peak period. There is limited room for overtime, but SCM has decided to use this to absorb short-term fluctuations in demand.

Other options to vary capacity during the seasonal cycle are subcontracting or carrying excess machine capacity during the off-peak season (Ketzenberg, Metters and Semple 2006).The seasonal fluctuations are experienced industry wide and therefore subcontracting is not a solution. The number of machines is not increased because the investment intensity is high. SVI aims to make efficient use of its capital goods and carrying excess capacity during the off-peak periods is therefore not an option. Because the options to pursue a chase strategy are not applicable SVI pursues a level strategy.

6.1.2 Build up

To reduce the complexity we express production and demand in an aggregate measure e.g. the number of machine hours. The starting point for the built up of stock is such that it allows cumulative production to match cumulative demand. Demand (Production) is cumulative over time. E.g. there is no need to start to produce beyond to immediate needs in January if there is capacity beyond the immediate needs in February and March that allow a sufficient build up.

This is best explained by Figure 6.1-1. It has a seasonal peak in Augustus and September (300 and 350 hours). To fulfill demand in those months capacity needs to be stored in advance because the production capacity in this example is constraint to 250 hours. Production strategy A starts building up to soon. This results in inventory holding costs on 750 hours. Production strategy B starts building up later on. This results in inventory holding costs on 150 hours. Note that both strategies fail to build up sufficient anticipation stock. This results in penalty costs on 150 hours (In this example the demand is backlogged). Also note from Figure 6.1-1 that the penalty costs incurred in September and October might be smaller than the extra holding costs. E.g. consider production strategy B producing 50 hours extra in April and 50 hours less in November. This would mean extra holding costs on 50 hours from April until Augustus (+250 hours in total) and 50 hours less penalty costs in September and October (-100 hours in total).



	Σ Demand	Σ Production		Inventory		Shortage	
		A	B	A	B	A	B
Jan	150	200	150	50	-	-	-
Feb	300	400	300	100	-	-	-
March	450	600	450	150	-	-	-
April	650	800	650	150	-	-	-
May	850	1.000	900	150	50	-	-
June	1.100	1.200	1.150	100	50	-	-
July	1.350	1.400	1.400	50	50	-	-
Aug	1.650	1.650	1.650	-	-	-	-
Sep	2.000	1.900	1.900	-	-	100	100
Oct	2.200	2.150	2.150	-	-	50	50
Nov	2.300	2.300	2.300	-	-	-	-
Dec	2.400	2.400	2.400	-	-	-	-
Total				**750**	**150**	**150**	**150**

Figure 6.1-1 **“Cumulative Demand and Production”**

6.1.3 Multiple Articles

In the previous section we considered aggregate demand and production. The aggregate production plan needs to be translated to individual articles. Some articles have lower holding costs than other articles. This makes it cheaper to build anticipation stock in these articles. The production of the high holding cost articles is then deferred as long as possible. If anticipation stock is not properly divided over the articles e.g. too much stock on low holding cost articles or in aggregate not enough we cannot satisfy all demand resulting in penalty costs. This leaves us with two three questions 1) when to start the built up of anticipation stock and 2) which articles to use for the building of stock and 3) how to divide the capacity if we cannot satisfy all demand.

6.2 Literature Review

We have searched the available literature for articles that answer the questions 1) when to start the built up of anticipation stock and 2) which articles to use for the building of stock and 3) how to divide the capacity if we cannot satisfy all demand. Another criterion was that the key-features of the articles preferable resemble the situation on-hand. We therefore searched the available literature using the following combination(s) of key-words: multi-item (or multi-product), seasonal, setups, capacity, constraint and production. To the best of our knowledge there are no scientific articles that match all criteria.

We excluded setups from the list of keywords and found an article of (Metters 1998). The key features are multiple articles, seasonal stochastic demand, a general capacity constraint and lost sales. (Metters 1998) presents a dynamic programming model to calculate the optimal solution. The optimal solution times are exponentially increasing in the number of articles and therefore not suitable for solving realistic problems. (Metters 1998) therefore reviews the performance of two heuristics: a proportional and fixed safety stock heuristic. In the proportional safety stock heuristic the safety stock is proportional to expected demand e.g. expected demand +10% in a given period means safety stock +10% in that period. In the fixed safety stock case only the expected demand varies. The expected demand (in a given period) plus the safety stock serves as target produce up-to level in both heuristics. The produce up-to level is on-hand stock after production, but before demand. Whether the produce up-to level is within reach depends on the general capacity constraint. The production quantities are determined using Linear Programming (LP). The performance of the heuristics is compared to optimality only for the two article case.

(Ketzenberg, Metters and Semple 2006) compare a fair share heuristic, the proportional and fixed safety stock heuristic to a marginal analysis (MA) heuristic they developed. In the fair share heuristic the target produce up-to level is calculated using a ‘newsboy’ equation. If the target produce up-to level is not within reach, capacity is allocated. The difference between the on-hand stock level at the start of the period and the target produce up-to level determine the capacity each article needs. The ‘fair share’ heuristic gives each article capacity in proportion to the capacity needed. The performance of the heuristics is again compared to optimality for the two article case. The MA heuristic deviates from optimality only by 1.7%. This is an improvement compared to the other heuristics. In an experimental design for 6, 12 and 24 articles the MA heuristic continued to outperform the other heuristics and showed no signs of deterioration as the number of articles increased.

The literature review in (Ketzenberg, Metters and Semple 2006) revealed that (Kapuscinski and Tayur 1998) investigated the single-item, seasonal case with a capacity constraint. The literature review in (Ketzenberg, Metters and Semple 2006) does not refer to articles that handle the multi-item case with seasonal demand and a capacity constraint. We were also unable to find them ourselves and therefore decided to adopt the article of (Ketzenberg, Metters and Semple 2006) as the basis of our project.

6.2.1 Summary

The main reasons to select the article of (Ketzenberg, Metters and Semple 2006) was that it answered 1) when to start the built up of anticipation stock and 2) which articles to use for the building of stock and 3) how to divide the capacity if we cannot satisfy all demand. Others reasons to select their article are a) they propose a heuristic that deviates from the profitability of the optimal policy by only 1,7% b) their heuristic is an improvement compared to the fair share, the proportional and fixed safety stock heuristic c) their heuristic shows no signs of deterioration in performance as the number of articles increases. The disadvantage is that the MA heuristic (or any of the other heuristics) does not include setups.

6.3 Basic Idea KMS

In this section we will discuss the basic idea of the dynamic programming model and the MA heuristic developed of (Ketzenberg, Metters and Semple 2006) (KMS).

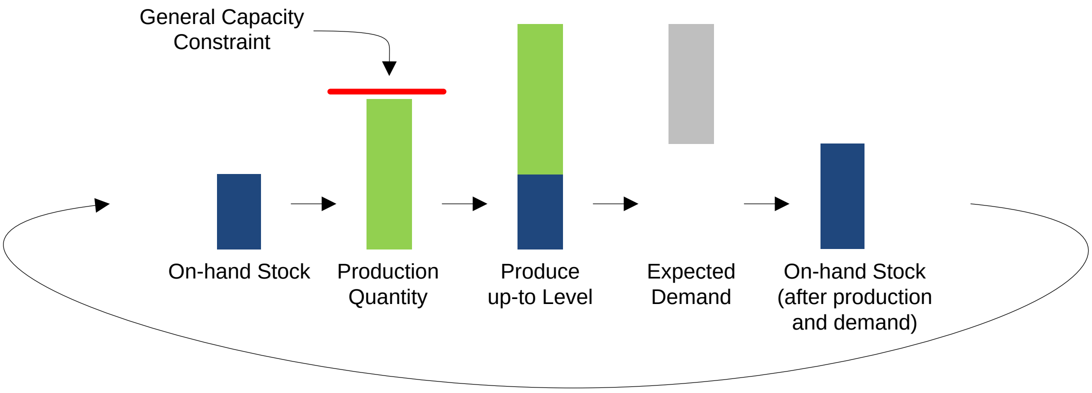

General Capacity Constraint
On-hand Stock
Production Quantity
Produce up-to Level
Expected Demand
On-hand Stock (after production and demand)

Figure 6.3-1 **"Basic Idea KMS"**

6.3.1 Dynamic Programming Model

The basic idea of the dynamic programming model presented by (Ketzenberg, Metters and Semple 2006) is depicted in Figure 6.3-1. We go from left to right and will first consider a single article. We start with on-hand stock in a given month. Based on holding costs, penalty costs and the demand distribution function the dynamic programming model decides on the production quantity. Together with the on-hand stock this results in the produce up-to level. Based on again the demand distribution function the dynamic programming model calculates the expected demand. The produce up-to level minus the expected demand results in the new on-hand stock level. This is the on-hand stock we will start the next month with.

Now consider the same figure in the peak period. The dynamic programming model again decides on the production quantity. The model wants to reach a 'high' produce up-to level because it expects 'high' demand (we are in the peak period). The general capacity constraint however prohibits a large production quantity. This will result in large expected penalty costs. The dynamic programming model attempts to avoid this by going back one month and increase the production quantity in that month. This will result in more on-hand stock at the start of the current month. This means that a higher produce up-to level is within reach and the expected penalty costs are reduced at the expense of extra holding costs.

Now consider the following. The dynamic programming goes one month back to increase the production quantity in that month in order to avoid penalty costs. However in this situation we have already reached the general capacity constraint in the previous month. This means we have to go back another month. If the model can increase the production quantity in that month penalty costs are reduced in the current month at the expense of extra holding costs in two months. This process can be repeated by going more months back if necessary.

Introducing two or more articles would mean that the model would also have to decide on the increase of the production quantity of each single article. This becomes very complex. (Ketzenberg, Metters and Semple 2006) estimate that to calculate the optimal production quantities for 12 months would require weeks of CPU time even in the 4 article case. In the problem on hand we have more than 600 articles.

6.3.2 Marginal Analysis Heuristic

The MA heuristic of (Ketzenberg, Metters and Semple 2006) starts by calculating the optimal produce up-to level in each period for each article. They do this with a similar dynamic program as depicted in Figure 6.3-1 only without the general capacity constraint. After the optimal produce up-to levels are calculated the MA heuristics checks if they are within reach if we do consider the capacity constraint.

E.g. consider three months. In the first two months the optimal produce up-to level is within reach in the last month not. In the first month the MA heuristic will produce up to the optimal level. After the optimal produce up-to level is reached there is still capacity. The MA heuristic will then check if the optimal produce up-to level is within reach in the next month. Because the optimal produce up-to level is also within reach the next month, the MA heuristic will check if the optimal produce up-to level is within reach in the third month. The MA heuristic could decide to produce articles for the third month in the current month. The MA heuristic however first checks if the optimal produce up-to level in the third month is within reach by using to capacity surplus in the second month. This is the case and no articles for the third month are produced in the first month.

In the second month we do need to start producing for the third month. After the optimal produce up-to levels in the second month are reached, the remaining capacity is divided using marginal analysis. Marginal analysis divides the remaining capacity over equally lengthened step sizes e.g. a step size of 1 hour. The MA heuristic will then decide for which article it is most profitable to spend the next hour on. Hereafter the heuristic will decide for which article it is the most profitable to spend the second next hour on. This process is repeated until the remaining capacity is given away or the optimal produce up-to levels for the third month are within reach. The advantage of marginal analysis is that it considers the marginal costs, marginal profits and the demand distribution function of each individual article (Ketzenberg, Metters and Semple 2006).

Now consider the following. The demand in the second month was much higher than expected and the on-hand stock for all articles is reduced to zero. This means that the optimal produce up-to levels in the third month are no longer within reach. The MA heuristic will then use marginal analysis to decide how to allocate the available capacity.

6.4 Assumptions KMS & Adaptations

In the next section we will review the assumptions made by (Ketzenberg, Metters and Semple 2006). If the assumptions do need hold we will adapt the MA heuristic. The key assumptions are listed below:

1. The demand distribution function of each article in each period is known.
2. The anticipation stock for an article is not sold until the peak demand period.
3. Lost Sales
4. No setup costs or setup times
5. Demand does not occur before production has finished.
6. No disposal or deterioration of inventory
7. The demand is independent across articles.

6.4.1 Assumption 1: Demand Distribution

This assumption does not hold. We are unaware of the (cumulative) distribution functions of demand because the non-stationarity of demand prohibits us to make an exact analysis of the distribution function in each time period. See also Chapter 4. This means we cannot calculate the optimal produce up-to level in each month for each article using a dynamic programming model. This means that we also cannot calculate the expected capacity shortage in each month.

We do have detailed information in the short term based on 1) the order book and 2) a judgmental forecast made by Sales and Marketing on a limited set of (MTS) articles. Based on this information, we will calculate the optimal produce up-to level in the short term using a ‘newsboy’ equation. The shortage in the future months will be forecasted. The forecasted shortage is an aggregate number for each month based on the actual demand in the same month last year. The actual demand in this year can deviate from last year’s. The aggregate forecast can therefore be revised judgmentally.

6.4.2 Assumption 2: Anticipation Stock and Demand

(Ketzenberg, Metters and Semple 2006) assume that the anticipation stock built up for future months can be sold in the current month. We agree. They also assume that in the other months until the peak month the anticipation stock is not sold. In the remainder of this section we will show why this assumption does not strictly hold in our adapted MA heuristic.

If the MA heuristic of (Ketzenberg, Metters and Semple 2006) detects a shortage in a future month it will allocate the limited capacity in that month using marginal analysis. Any articles not produced up to the optimal level in the future month, because of the limited capacity, can be produced in an earlier month. We do not have detailed demand information for this future month. This means we cannot allocate the capacity in the future month.

We do have detailed information in the short term. We will use this information to anticipate to the capacity shortage in the future month. This creates a cascading effect. E.g. the detailed demand information is known two months in advance. The MA heuristic will built up stock based on the detailed demand information. In the current month stock is build based on the detailed information for the second month. This will be sold in the second month. This results in (extra) surplus capacity in the second month. The order book gets filled over time and the MA heuristic can again built up stock based on the 'known' demand. In the second month stock is build based on the detailed information for the third month. This process can be repeated. Once arrived at the month with the shortage the demand can be allocated, using marginal analysis, based on detailed information that is known by then.

Because in our adapted MA heuristic anticipation stock can be sold in the meantime we do assume that is replaced by an article that requires an equal amount of time to produce and have equal holding and penalty costs. The latter assumption ensures that the calculations made to select the article for building stock remain valid.

6.4.3 Assumption 3: Lost Sales

This assumption does not hold. Recall from Chapter 3 that we assume only demand for standardized articles to be lost because the customer has the option to buy the standardized article from a competitor. Standardized articles are MTS. We can ensure that the assumption holds by giving priority to the order book in the current month. We assume the order book to not include forwarded orders for standardized articles because the customer has no incentive to order the article forward if he can buy it anyhow from a competitor.

6.4.4 Assumption 4: No Setups

This assumption does not hold. Recall from Chapter 5 that the effective production time is <<confidential>>% of the available capacity. The setups consume <<confidential>>% of the available capacity, a considerable amount compared to the effective production time. The operational planners can decide on the amount of setups. We will therefore adjust the dynamic programming model and heuristic of (Ketzenberg, Metters and Semple 2006) to incorporate the **time** consumed by setups. Note there are small and large setups; small setups within a routing group and large setups between routing groups. A routing group is a set of articles that share the same mold. A small setup corresponds to a mixture change and a large setup to a mold change.

In the problem on hand the setups are carried out by 'regular' personnel. This means that the total **costs** in the short term are not directly affected by the setup policy. The 'regular' personnel need to be paid whether they operate the machine for production, setup the machine or wait. The setup time however reduces the time that can be spent on effective production and under heavy utilization this can lead to stock outs. The setup costs therefore are a function of the setup time and production rate -this determines the number of units short-, and penalty costs per unit in case of stock outs.

The MA heuristic works based on marginal analysis. Marginal analysis divides the available capacity over equally lengthened step sizes. In case the heuristic selects an article that has not been produced we incur a setup time and the derived setup costs. Whether it is still profitable to produce an article less or only the step size depends on the setup costs. To avoid that an article is not selected because of these setup costs we will **not incorporate setup costs** in the heuristic. We will however adapt the heuristic to **avoid setups** if possible.

First, we will allow at the most one large setup for each routing group and at the most one small setup for each article per month.

Second, we avoid setups by introducing a production threshold to the original MA heuristic. An article can only be setup if the time that an article can be produced is longer than the threshold. The time that an article can be produced depends on the difference between the on-hand stock and the target produce up-to level. If an article does not exceed the threshold, the optimal produce up-to level is reduced to the on-hand stock. In the remainder of this project we will not vary the threshold and set it on 1 hour. This is reasonable based on the experience of the project manager. The threshold is ignored if an article needs to be produced because it is due in the order book in the current month.

Third, consider a situation where the optimal produce up-to levels cannot be reached for all articles but some articles are setup because they are due in the order book in the current month. In those cases we avoid setups by producing up to the optimal levels for the articles that are already setup. At first we will ignore the articles not already setup. This might be suboptimal in the short run. However not producing up-to the optimal levels for the articles already setup and dividing the available capacity means more setups. This might be suboptimal in the longer run because in the next month several articles might need to be setup again.

Fourth, we will avoid setups by limiting the list of articles that can be produced in anticipation of a future shortage to the articles that are already setup in the current month. At first we will again ignore the articles not already setup. This again might be suboptimal in the short run. Dividing the anticipation stock over more articles means more setups but will also diminish the probability of stock outs in the short run. This is best explained by an example also used by (Bertrand and Wijngaard 1986). Consider article A and B. Both articles have identical production and demand characteristics. Compare a state with produce up-to levels {A + anticipation stock, B} and {A + ½ anticipation stock, B + ½ anticipation stock}. In the short run the risk of stock outs in the former state is higher. In the longer run the states are identical. The advantage is that we avoided a setup in the former state.

At a certain point an extra setup becomes unavoidable. In the third case an article needs to be setup because the optimal produce up-to level for the other articles is reached. The next article will be selected based on a ratio. The ratio measures the maximum penalty costs that can be avoided if that article is setup vs. the time needed for effective production, small setup and an optional large setup. The article with the highest ratio is selected.

In the fourth case an article needs to be setup because the optimal produce up-to level in the future period is within reach for all articles with the current production quantities. The next article will again be selected based on a ratio. The ratio measures the maximum holding costs that are incurred if the article is setup vs. the time needed for effective production, small setup and an optional large setup. The article with the smallest ratio is selected.

It is also possible that the quantities due in the order book are not within reach for all articles. In those cases the next article is setup based on the penalty cost ratio. The maximum produce up-to level that can be reached in those situations is reduced to the quantity due in the order book.

6.4.5 Assumption 5: Demand before Production

(Ketzenberg, Metters and Semple 2006) assume demand occurs after production of all articles within a month has finished. If we translate this assumption to the problem on hand the assumption is generally valid only if demand occurs at the end of the month. Demand however occurs on a day-to-day basis. The assumption only holds if the production planners are able to schedule the planned production of articles such that they are ready before the demand occurs.

If the assumption does not hold in practice 1) production of all articles might need to be shifted forward to avoid penalty costs. This means extra holding costs. Another option is 2) extra setups. This means that more time is consumed than planned for. This might lead to extra penalty costs under heavy utilization. Note that in the problem on-hand the customers rarely request timely delivery and this makes it more likely that the assumption holds. Note that this also means extra holding costs.

6.4.6 Assumption 6: No Disposal or Deterioration

This assumption holds. Articles are stored outside subject to weather conditions. Under the influence of among other sunlight the color of certain articles fades. The amount of fading i.e. color deterioration depends on the color admixtures used and the time exposed. This makes certain articles less suitable for the building anticipation stock. The articles that use color admixtures however have higher than average holding costs and are likely to be MTO. This means that the MA heuristic is unlikely to select these articles. It selects based on holding costs and MTO demand is only known in the short term. To further decrease the probability, the end user can manually increase the holding costs.

6.4.7 Assumption 7: Independent Demand

The assumption does not hold in a broad sense. First there are articles that are almost identical in look and feel e.g. both red and equal in size but different in mixture type. This means there is a substitution effect. Second certain articles are complimentary to each other e.g. tiles are laid in a pattern that consists of ‘halve’ and ‘whole’ tiles. Both the ‘half’ and ‘whole’ tiles have different article numbers but their demands are correlated. The heuristic is unaware of the substitution effects. E.g. there is insufficient capacity to reach all the quantities due in the order book. The heuristic selects an article to produce while the substitute is ready available in the on-hand stock. Or the heuristic selects an article to produce without selecting the complimentary article. Both situations would be suboptimal. We will however continue with the assumption because the heuristic gives priority to the order book. This mitigates the substitution effect because once the customer has ordered he will not choose for a substitute article and we assume he has also ordered the complementary article. Second, the heuristic only proposes to produce certain articles. The production planner has the option to intervene.

6.5 Conclusion

We have searched the available literature and found an article of (Ketzenberg, Metters and Semple 2006). The problem they describe resembles the problem on-hand. First, they develop a dynamic programming model. This model cannot be used for realistic problem size. They therefore developed a marginal analysis heuristic. They compare the MA heuristic against other heuristics and the optimal solution in the two article case. The MA heuristic performs better than the other heuristics and close to the optimal solution. It shows no signs of deterioration if the number of articles is increased. This is important because in the problem on-hand we have over 600 articles. The advantage of marginal analysis is that it considers the marginal costs, marginal profits and the demand distribution function of each individual article (Ketzenberg, Metters and Semple 2006).

In the last section we reviewed the assumption made by (Ketzenberg, Metters and Semple 2006). Not all assumption hold and we present several adaptations. The main adaption is the introduction of setups to the original MA heuristic. We are especially interested in the time consumed by setups because this diminishes the time that can be spent on effective production. This can lead to penalty costs under heavy utilization. The expected penalty costs can be translated to setup costs. In our adapted heuristic we will however not incorporate setups costs. It is possible that an article requires a setup because it is just under e.g. 1 unit under the optimal produce up-to level. It is also possible that the setup costs cannot be earned back within the step size. The heuristic would therefore not select the article in these cases. In case there is ‘enough’ time there is however no reason to avoid setups. However by not incorporating setup costs we risk that heuristic is overly enthusiastic in setting up articles (and consuming time). To prevent this we will adapt the heuristic such that it avoids setups if possible.

7 Model & Heuristic

In this chapter we will first introduce the dynamic programming model of (Ketzenberg, Metters and Semple 2006). Their dynamic programming model cannot be used for realistic problem sizes. We will add setups to their model. This means that our dynamic programming model also cannot be used for realistic problem sizes because it is even more complex. In the second section we will therefore present an adapted version of the MA heuristic of (Ketzenberg, Metters and Semple 2006). The basic idea of the adaptations can be found in Chapter 6. In the second section the adaptations will be presented in detail. In the last section we will arrive at conclusions.

The model variables are defined at first use. An overview of all model variables used can be found in Chapter 15.

7.1 Mathematical Description

In this section we present the dynamic programming model developed by (Ketzenberg, Metters and Semple 2006) and we introduce setups to their model. First, we will introduce the model variables used. Second, we will present equations 7.1 and 7.2 that are integrally adopted. Third, we will introduce a new capacity constraint. This constraint is introduced because setups consume time a limit the time that can be spent on effective production.

7.1.1 Model Variables

The subscripts for the time period t and article a are suppressed if the context is clear.

A:	Set of articles, index $a, a \in \{1 \dots N\}$
c_a:	Production cost per unit for article a
TP:	Set of time periods, index $t, t \in \{1 \dots T\}$
f_t:	Minimum expected total cost function for periods $t, t+1, \dots, T$
G_t:	Single-period holding and lost sales cost function
h_a:	Holding cost per period per unit of article a
i_{ta}:	On-hand stock of article a before production, before demand in period t (units)
m:	Arbitrary value for demand x.
r_a:	Capacity per unit required to produce article a (hours)
R_t:	Time available for production in period t
v_a:	Revenue per unit for article a
x_{ta}:	Demand for article a in period t (units)
y_{ta}:	Optimal produce up-to level of article a in period t (units)
π_a:	Lost sales penalty cost per period per unit in excess of lost profit for article a
$\phi_{ta}(x_{ta})$:	Probability density function for demand x_{ta}
$\Phi_{ta}(x_{ta})$:	Cumulative distribution function for demand x_{ta}
$(value)^+$:	Maximum $(0, value)$

7.1.1.1 Articles

We have production data from the M1 in Tiel from 2006, 2007 and 2008. The set of articles A consists of articles produced in 2007 and 2008. The actual set of articles can change because articles can be allocated to or from another machine to the M1 and because of the introduction of new articles. However re-allocations are bounded by mold availability on machines and the mixture process at the location. The introduction of new articles is likely to be offset by the outflow of old articles. We therefore assume that the article set produced in 2007 and 2008 is the best predictor of the articles to be produced in the near future.

7.1.1.2 Periods

We will use time periods of one month. Dependent on the environment other time periods can be used (day, week, quarter).

7.1.1.3 Production Costs

The production cost we use are in SAP. The production cost in SAP include e.g. overhead, raw materials, labor etc. We will not discuss the system that is used to determine the production cost because that would be beyond the scope of this project.

7.1.1.4 Holding costs

Holding costs reflect the costs of holding (excess) inventory. The holding costs include: the labor to operate the inventory space, the cost of capital on the amount invested on inventory, damages by weather (color deterioration) or handling and the risk of insolvency. CRH -the parent company- has given SVI a RONA target of 15% per year. We assume that the RONA target reflects the underlying business risks and costs of SVI, including the costs and risks of holding inventory. We will therefore use yearly holdings costs of 15%, or $15\%/12 = 1{,}25\%$ per month. The holding costs are calculated based on the production cost. E.g. with a unit production cost of 10 euro for article a this would give inventory holding cost $h_a = 1{,}25\% * 10 = 0{,}125$ euro per unit per month.

7.1.1.5 Penalty Costs in Excess of Lost Profit

Penalty costs reflect the costs of not enough inventories. Penalty costs in excess of the lost profit include: the loss of goodwill because the customer might not (attempt to) order again in the future and the loss of contribution margin for (complementary) articles that also remain unordered. Because we do not know these effects the penalty costs in excess of lost profit are not set and hence they are zero. The tool will however allow the introduction of penalty costs in excess of lost profit.

7.1.1.6 Production Rate

Recall from Chapter 5 that the production rate depends on the routing group of the article. The production rate for an article is the average production rate for the corresponding routing group. We base the production rate on 2008. E.g. article a belongs to routing group g. The number of units produced in 2008 in routing group g is 10.000 and the number of production hours spend on routing group g is 10. This would give $r_a = 10/10.000 = 0{,}001$ hours per unit.

7.1.1.7 Revenue

The average revenue per unit in 2007 and 2008 for articles in A. Recall that our article set A consists of articles produced in 2007 and 2008. We take an average because SVI has different sales prices for different customers.

7.1.2 Dynamic Programming Model

$$f_t(i_{t1}, i_{t2}, \dots, i_{tN}) = MIN\left\{\sum_{a=1}^{N} c_a(y_{ta} - i_{ta}) + G_t(y_{t1}, y_{t2}, \dots, y_{tN}) + \sum_{(x_{t1},x_{t2},\dots,x_{tN})} f_{t+1}((y_{t1}-x_{t1})^+, \dots, (y_{tN}-x_{tN})^+) \prod_{a=1}^{N} \phi_{ta}(x_{ta})\right\} \qquad (7.1)$$

The dynamic programming model (Ketzenberg, Metters and Semple 2006) present, is denoted by equation 7.1. The objective of equation 7.1 is to minimize total costs in the current and future time periods. The first term of equation 7.1 denotes the production costs, the second term - function G_t- the single-period holding and lost sales cost, and the latter term are the expected costs for the future periods. In the latter term equation 7.1 is applied again. This is consistent with Figure 6.3-1 which is also repeated over time.

The decision that needs be made in each period is how much to produce of each article. The decision depends on the on-hand stock at the start of the time period; the vector of on-hand inventory levels $(i_{t1}, i_{t2}, \dots, i_{tN})$. The decision is denoted by the vector of produce up-to levels $(y_{t1}, y_{t2}, \dots, y_{tN})$. The produce up-to levels affect the production costs, the holding and lost sales cost and the starting stage for the next time period.

7.1.2.1 Holding and Lost Sales Cost

The single period holding and lost sales cost -function G_t- used in equation 7.1 is presented in equation 7.2. It describes the costs based on the optimal produce up-to level (y) and arbitrary demand value (m). The first term within the brackets represent demand values smaller than the inventory level $(m \leq y)$. It describes the total holding costs minus the revenues. Revenue is treated as a negative cost. The second term represents demand values larger than the inventory level $(m > y)$ describes the total penalty costs minus the revenues.

$$G_t(y_{t1}, y_{t2}, \dots, y_{tN}) = \sum_{a=1}^{N}\left[\sum_{m=0}^{y_{ta}} (h_a(y_{ta} - m) - v_a m)\phi_{ta}(m) + \sum_{m>y_{ta}} (\pi_a(m - y_{ta}) - v_a y_{ta})\phi_{ta}(m)\right] \qquad (7.2)$$

7.1.2.2 Capacity Constraint

In the model of (Ketzenberg, Metters and Semple 2006) equation 7.1 is constrained by equation 7.3. It ensures that the total hours spent on production do not exceed the total hours available for production. Recall the common capacity constraint in Figure 6.3-1.

$$\sum_{a=1}^{N} r_a(y_{ta} - i_{ta}) \le R_t \qquad \forall t, a \qquad (7.3)$$

7.1.2.3 Setups

The dynamic programming model of (Ketzenberg, Metters and Semple 2006) assumes no setup times. We introduce setups to their model. We aim to avoid setups if possible. We assume that if a product is produced in a period it will require at the most one setup. This is reasonable for the problem on-hand because we will use time periods of one month and in the current situation the average time between two consecutive setups on a routing group is <<confidential>> days. See also 0. We will present a new capacity constraint 7.4 that will replace constraint 7.3. But first we introduce the model variables used in 7.4.

A_g: Subset of A, articles in routing group g

RG: Set of routing groups, index $g, g \in \{1 \dots Q\}$

k: Setup time required if no change of routing group is necessary (hours)

l: Extra setup time required if a change of routing group is necessary (hours)

b_{ta}: Binary variable taking value 1 if article a is produced in period t, and 0 otherwise

d_{tg}: Binary variable taking value 1 if an article from routing group g is produced in period t, and 0 otherwise

$$\sum_{a=1}^{N} r_a(y_{ta} - i_{ta}) + k\sum_{a=1}^{N} b_{ta} + l\sum_{g=1}^{Q} d_{tg} \le R_t \qquad \forall t, g, a \qquad (7.4)$$

$$b_{ta\le}d_{tg} \qquad \forall t, g, a \in A_g \qquad (7.5)$$

Equation 7.4 ensures that the total hours spent on effective production, small setups and large setups does not exceed the total time available for production in period t. Equation 7.5 ensures that for each article setup there is also a group setup for the routing group the article belongs to. Equation 7.1 is now constrained by 7.4 and 7.5.

7.2 Marginal Analysis Heuristic

The dynamic programming model of (Ketzenberg, Metters and Semple 2006) cannot be used for realistic problem sizes. We have added setups to their model. This means that our dynamic programming model also cannot be used for realistic problem sizes because it is even more complex. In this section we will describe an adapted MA heuristic. The basic idea is similar to the original heuristic of (Ketzenberg, Metters and Semple 2006).The adaptations are listed in section 7.2.1. We will explain why and where our heuristic is different. In section 7.2.2 we will give an overview of the adapted MA Heuristic. In section 7.2.3 we will explain how we calculate the optimal produce up-to level. In section 7.2.4 we will give a detailed description of our MA heuristic.

7.2.1 Adaptations

The heuristic we present differs in four points from the original heuristic.

1. In the original heuristic stock outs result in lost sales. In the problem on-hand only demand for standardized articles is lost. The customer is willing to wait for the other articles that are not delivered timely. We assume that the standardized articles are not in the order book. To resemble to original heuristic we give priority to the quantities due in the order book in the current month.
2. The original heuristic calculates the optimal produce up-to level for each article in each month using a dynamic programming model. This requires detailed demand information for all months. We have detailed demand information in the short term. Our heuristic calculates the optimal produce up-to level in the short term by using a ‘newsboy’ equation.
3. Our heuristic attempts to avoid setups. We only setup an article if the time that an article can be produced is longer than the threshold. The time that an article can be produced depends on the difference between the on-hand stock and the target produce up-to level. If an article does not exceed the threshold, the optimal produce up-to level is reduced to the on-hand stock. The threshold is ignored if an article needs to be produced because it is due in the order book in the current month.
4. Our heuristic takes the time small and large setups consume into account.

7.2.2 Overview

1. See also Figure 7.2-1. Our heuristic gives priority to the quantities due in the order book in the current month. If the quantities are not within reach the available capacity needs to be allocated among the articles. This is done by evoking Procedure Allocate. This procedure is explained in section 7.3.
2. If the quantities due are within reach the MA heuristic attempts to reach all the optimal produce up-to levels in the current month. If the levels are not within reach, the available capacity needs to be allocated among the articles.
3. If the optimal produce up-to levels for the current month are within reach the marginal analysis heuristic looks ahead and attempts to anticipate to future shortages. This procedure is explained in section 7.3.

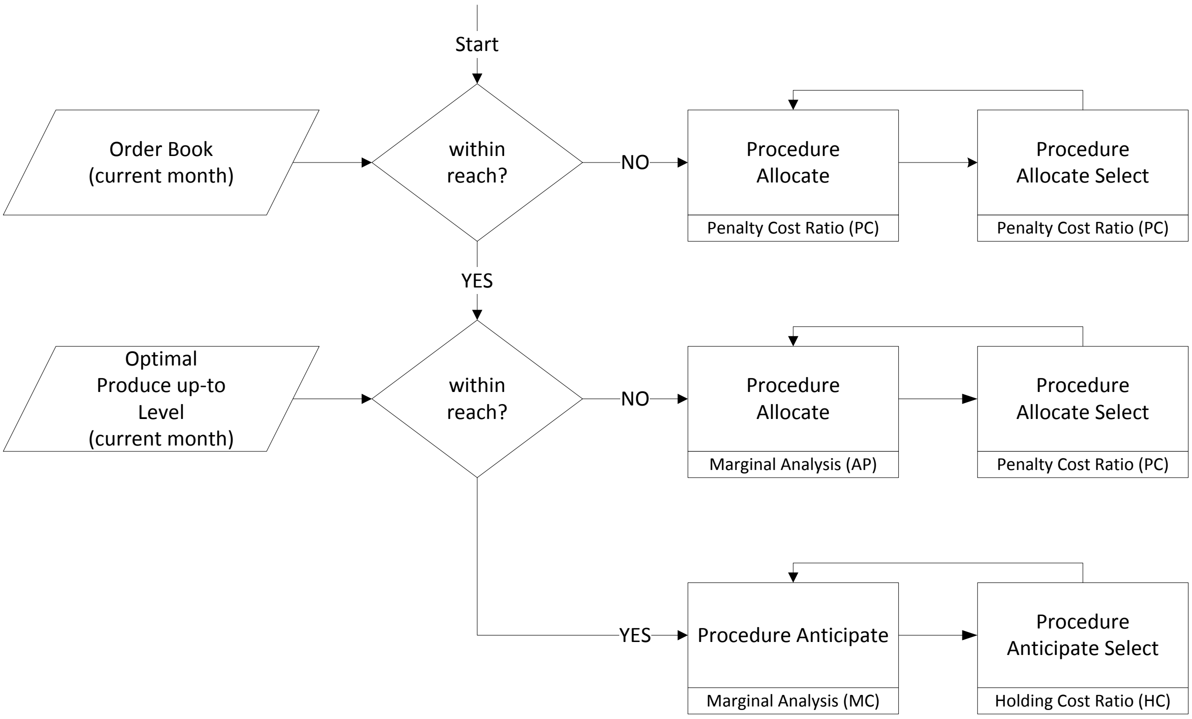

Start
Order Book (current month)
within reach?
NO
YES
Procedure Allocate
Penalty Cost Ratio (PC)
Procedure Allocate Select
Penalty Cost Ratio (PC)
Optimal Produce up-to Level (current month)
within reach?
NO
Procedure Allocate
Marginal Analysis (AP)
Procedure Allocate Select
Penalty Cost Ratio (PC)
YES
Procedure Anticipate
Marginal Analysis (MC)
Procedure Anticipate Select
Holding Cost Ratio (HC)

Figure 7.2-1 **"Flowchart MA Heuristic"**

7.2.3 Optimal Produce up-to Level

The optimal produce up-to level is different for each article in each month. The optimal produce up-to level is calculated using a 'newsboy' equation (Silver, Pyke and Peterson 1998). The optimal produce up-to level is denoted by S^{∞}. See also equation 7.6. It is used to calculate the optimal probability that the demand is equal or smaller than the produce up-to level. Each month has a general capacity constraint. This means that the optimal produce up-to level may not be in reach. The produce up-to level that can be reached is denoted by S.

7.2.3.1 Variables

S_{at}^{∞}: Optimal produce up-to level of article a in period t, without considering the general capacity constraint (units)

S_{at}: Optimal produce up-to level of article a period t (units)

x_{ta}^{-}: Demand for article a due in period t based on the order book (units)

x_{ta}^{+}: Maximum demand for article a in period t based on the order book and a judgmental forecast (units)

$Pr(\quad)$: Denotes a probability

7.2.3.2 Newsboy Equation

$$Pr(x < S^{\infty}) = \frac{\pi + (v - c)}{\pi + (v - c) + h} \qquad (7.6)$$

7.2.3.3 Cumulative Distribution Function

To calculate the optimal probability in equation 7.6 we use the inverse cumulative distribution function of the demand. Based on the input $\frac{\pi+(v-c)}{\pi+(v-c)+h}$ it returns the value of S^{∞}. We are however unaware of the (cumulative) distribution functions of the demand (x) because the non-stationarity of demand -as discussed in Chapter 4- prohibits us to make an exact analysis of the distribution function in each month. We can however present a lower limit and upper limit for each month. The lower limit $(x_{t^*}^-)$ is the quantity due in the order book in the current month. The upper limit $(x_{t^*}^+)$ is a judgmental forecast made by Sales or the marketing department. To show how the heuristic works we let the probability that x is equal to x^+decline at a steady rate on the interval$[x^-, x^+]$. We approximate the value of x by this assumption because we do not know the exact distribution functions. The probability function is known as the triangular distribution function, the equations that describe $\phi(x)$ and $\Phi(x)$ can be found in Appendix G.

7.2.4 Detailed Description

7.2.4.1 Variables

t^*: Denotes the current time period $(t^* = 1)$

R^+: Surplus capacity (capacity short) in period t^*

u: Production threshold, the minimum amount of time an article needs to be produced to justify a setup (hours)

$$R^+ = R_{t^*} - \sum_{a=1}^{N} r_a(S_{t^*a} - i_{t^*a}) + k\sum_{a=1}^{N} b_{t^*a} + l\sum_{g=1}^{Q} d_{t^*g} \tag{7.7}$$

Equation 7.7 resembles equation 7.4 and denotes the surplus capacity. R^+ should be seen as a temporary variable that declines as planned production increases. R^+ is negative when too much production has been planned for. The available capacity is denoted by the first term, effective production time by the second term, total time consumed by small setups by the third term and the total time by large setups in the last term. To avoid setups an article is only selected for production if it can be produced for a minimum amount of time (u). This threshold is ignored if the article needs to be produced because it is due in the order book in the current month.

7.2.4.2 Steps

Step MA1: Determine if the quantities due in the order book in the current period are within reach: $S_{t^*a} = \max(x_{t^*a}^-, i_{t^*a}), \forall a, a \in A$;
Calculate R^+; If $R^+ > 0$ go to Step MA2 else $S_{t^*a} = i_{t^*a}$ and go to Procedure Allocate . (Step MA1 gives priority to the quantities due.)
The arguments for Procedure Allocate are $[x_{t^*a}^-(\forall a), i_{t^*a}(\forall a)]$

Step MA2: Calculate the optimal produce up-to levels for all periods and articles based on equation 7.6: $S_{ta}^{\infty},\ \forall t, a,\ t \in t^* \dots t^* + 11, a \in A$

Step MA3: The optimal produce up-to level is reduced to the on-hand stock at the start of the period if it does not exceed the production threshold and is not produced because it is due in the order book. If $r_a(S_{t^*a}^{\infty} - i_{t^*a}) < u$ and $b_{t^*a} = 0$ then $S_{t^*a}^{\infty} = i_{t^*a},\ \forall a, a \in A$

Step MA4: Determine if the optimal produce up-to levels are in the current period are within reach: $S_{t^*a} = S_{t^*a}^{\infty}\ \forall a, a \in A$; Calculate R^+; If $R^+ > 0$ go to step MA5 else go to Procedure Allocate. The minimum start value for all articles is the quantity due in the order book.
$S_{t^*a} = \max(x_{t^*a}^-, i_{t^*a})$.
The arguments for Procedure Allocate are $[S_{t^*a}^{\infty}(\forall a), S_{t^*a}(\forall a)]$

Step MA5: There is sufficient capacity to reach all the optimal inventory levels in the current period therefore we will attempt to anticipate on future shortages and we go to Procedure Anticipate.

7.3 Procedure Allocate

In this section we will describe the adaptations made to procedure allocate. Note in Figure 7.2-1 that Procedure Allocate is evoked if the quantities due in the order book in the current month are not within reach or if the optimal produce up-to levels are not within reach. Procedure Allocate, allocates the available capacity based on marginal analysis. Marginal analysis divides the available capacity over equally lengthened step sizes e.g. 1 hour that are subsequently allocated to the articles. We will first discuss the adaptations made. Second, we will give an overview of Procedure Allocate. Third, we give a detailed description of the steps in Procedure Allocate. In the latter section we described the selection of the next article to be setup.

7.3.1 Adaptations

1. In (Ketzenberg, Metters and Semple 2006) all articles require one unit of capacity, to produce one unit of an article $(r_a = 1)$. The step size is one unit (of capacity). In our heuristic the production rate (r_a) varies over the articles. Therefore we introduce the step size (z) e.g. 1 hour. This allows us to allocate (anticipate) on a common unit of capacity.
2. In the original heuristic all articles can be produced. Our heuristic attempts to avoid setups. In Procedure Allocate we will only allow production for articles that are already setup. An article can be setup 1) because it was due in the order book in the current month 2) it was selected for a setup by Procedure Allocate Select. The articles that are already produced are in the so called 'eligible' list. If an article has reached the optimal produce up-to level it is removed from the list. This means that the list can get empty. If the list gets empty another article needs to be selected. This is done in Procedure Allocate Select. The next article will be selected based on a ratio. The ratio measures the maximum penalty costs that can be avoided if that article is setup vs. the time needed for effective production, small setup and an optional large setup. The article with the highest ratio is selected. Note that if Procedure Allocate is evoked because the quantities due in the order book are not within reach, there is at the most one article in the eligible list. With one article in the list Procedure Allocate works based on the penalty cost ratio and not on marginal analysis.

7.3.2 Overview

1. The Allocate Procedure starts by creating a list of articles that are already setup. Articles that have reached their maximum produce-up-to level are removed from the list. If there are no articles in the list but there is time available for production an article needs to be setup and added to the list. This is done by evoking Procedure Allocate Select.
2. The articles with the highest expect marginal increase in profit in the list is selected for production. As long as there is time available for production the procedure is repeated.

7.3.3 Detailed Description

Procedure Allocate is evoked either if 1) the quantities due in the order book are not within reach or 2) if the optimal produce up-to levels are not within reach. This is communicated by the arguments used to evoke Procedure Allocate. The maximum value that can be reached is $(x_{t^*a}^{-})$ or $(S_{t^*a}^{\infty})$ the start value is either (i_{t^*a}) or (S_{t^*a}). In the next sections we will use maximum value$(x_{t^*a}^{-})$ and start value (i_{t^*a}).

7.3.3.1 Notation

z: Step size (hours)

$AP(a, z)$: Additional profit for an extra step size z of article a

L_{t^*}: Subset of A, denotes the articles eligible to produce in time the current time period t^*

$$AP(a,z) = \left((v_a - c_a) + \pi_a\right) {}^{z}/_{r_a} - (h_a + (v_a - c_a) + \pi_a) {}^{z}/_{r_a} \, \Phi\left(S_{t^*a} + {}^{z}/_{r_a}\right) \tag{7.8}$$

The first term in equation 7.8 describes the penalty costs that can be avoided. Below the lower bound –the quantity due in the order book- the latter term is reduced to zero. This means the penalty costs are avoided for sure. The demand above the quantity due is not known for sure and depends on the distribution function. As S_{t^*a} increases, Φ increases –the maximum value is 1- it becomes more likely that penalty costs are no longer avoided but only lead to holding costs.

7.3.3.2 Steps

Step AL1: As long as there are resources we can continue: $R^{+} > 0$

Step AL2: Create the list of products eligible to produce in the current time period: $L_{t^*} = \{\forall a \in A | S_{t^*a} > i_{t^*a}\}$

Step AL3: If there is enough starting inventory we remove the article from the eligible list: If $S_{t^*a} \geq x_{t^*a}^{-}$, $\forall a, a \in L_{t^*}$ then $L_{t^*} = L_{t^*} - \{a\}$

Step AL4: If there are no articles in the eligible list we have to select an article to add to the list: If $|L_{t^*}| = 0$ go to Procedure Allocate Select

Step AL5: Select the article with highest additional profit from the list. $a_{max} = \arg\max_{\mathrm{a} \in \mathrm{L}_{t^*}}\left(AP(a,z)\right)$

Step AL6: Produce an extra step size of the selected article: $S_{t^*a} = S_{t^*a} + \max\left({}^{z}/_{r_a}, S_{t^*a} - x_{t^*a}^{-}\right)$ return to Step AL1. The maximum number of units that can be added depends on the step size and the difference to the desired produce up-to level.

7.3.4 Procedure Allocate Select

Procedure Allocate Select selects an article to be setup if the list of articles eligible to produce is empty. The article to be setup next is produced until the maximum value is reached or until there is no capacity left.

The total penalty costs that can be avoided are the costs over the interval $[i_{t^*a}, x^{-}_{t^*a}]$; the start and maximum value. The time needed for production on this interval depends on the production rate (r_a) and whether the article requires a large setup. Note that a small setup is always required. The article that avoids the most penalty costs per required time is selected and added to the list of articles eligible to produce.

7.3.4.1 Notation

W_{t^*}: Subset of A, denotes the articles that can be setup next in the current time period t^*

$PC(a, t^*)$: Penalty cost avoided per unit of production time for article a in the current time period t^*

$$PC(a,t^*) = \frac{(x^{-}_{t^*a} - i_{t^*a})\big((v_a - c_a) + \pi_a\big)}{r_a(x^{-}_{t^*a} - i_{t^*a}) + k + l\big(1 - d_{t^*g}\big)} \qquad (7.9)$$

Equation 7.9 is a ratio: the numerator describes the penalty costs the denominator the required time: the effective production time, a small setup and an optional large setup. The large setup is only needed if the routing group the article belongs to has not been setup.

Note that we do not consider the holding costs in equation 7.9 and produce up-to the maximum value. In case Procedure Allocate is evoked because the quantities due in the order book are not within reach there are no holding costs. In case Procedure Allocate is evoked because the optimal produce up-to level is not within reach this might lead to holding costs. Note that the optimal produce up-to level already takes holding costs into account. Not producing up-to the optimal level for each article might be more optimal in the short run. However dividing the capacity over more articles means more setups. This might be suboptimal in the longer run because in the next month both articles might need to be setup again.

7.3.4.2 Steps

Step AL_SE1: Create a list of articles that can be setup next: $W_{t^*} = \{\forall a \in A | i_{t^*a} < x^{-}_{t^*a}\}$

Step AL_SE2: Calculate the penalty cost / time ratio for all articles: $PC(a, t^*), \forall a \in W_{t^*}$

Step AL_SE3: Select the article with highest penalty cost avoidance ratio: $a_{max} = \arg\max_{a \in L_{t^*}}\big(PC(a, t^*)\big)$

Step AL_SE4: Add the article to eligible list: $L_{t^*} = L_{t^*} + \{a\}$

7.4 Procedure Anticipate

Note in Figure 7.2-1 that Procedure Anticipate is evoked if the optimal produce up-to levels are within reach and there is a capacity surplus to anticipate on an expected future shortage by building stock. Procedure Anticipate allocated the surplus capacity based on marginal analysis. We will first discuss the adaptations made to the heuristic of (Ketzenberg, Metters and Semple 2006). Second, we will give an overview of Procedure Anticipate. Third, we give a detailed description of the steps in Procedure Anticipate. In the latter section we described the selection of the next article to be setup.

7.4.1 Adaptations

1. If the original MA heuristic of (Ketzenberg, Metters and Semple 2006) detects a shortage in a future month it will allocate the limited capacity in that month using marginal analysis. This is done by evoking Procedure Allocate. Any articles not produced up to the optimal level in the future month, because of the limited capacity, can be produced in an earlier month. We do not have detailed demand information for this future month. This means we cannot allocate the capacity in the future month. We do have detailed information in the short term. We will use this information to anticipate to the capacity shortage in the future month.
2. Because we have only detailed demand information in the short term we have to forecast the future demand. Based on the forecasted demand we will calculate the expected future shortage. The forecasted demand is an aggregate number for each month based on the actual demand in the same month last year. The actual demand in this year can deviate from last year's. The aggregate forecast can therefore be revised judgmentally.
3. (Ketzenberg, Metters and Semple 2006) argue that the anticipation stock built up for future months can be sold in the current month. We agree.
   They however assume that in the other months until the peak month the anticipation stock is not sold. We disagree. We build up stock based on the detailed information in the short run. This means it is likely those articles are sold in the short term. Because in our adapted MA heuristic anticipation stock can be sold in the meantime we do assume that is replaced by an article that requires an equal amount of time to produce and have equal holding and penalty costs. The latter assumption ensures that the calculations made to select the article for building stock remain valid.
3. Because the anticipation stock can be sold in the current month (Ketzenberg, Metters and Semple 2006) subtract the possibly avoided penalty costs in the current period from the costs of holding anticipation stock. We argue that because the anticipation

stock can be sold in all months until the peak period that to be consistent the possibly avoided penalty costs in all these months would need to be considered. We realize that this is far too complex for the purpose; an estimate of the extra holding costs. To be consistent we only consider the holding costs and not the possibly avoided penalty costs in any month.

7.4.2 Overview

1. Procedure Anticipate starts by looking one month ahead. The number of months that is looked ahead is increased until we look 11 months ahead. Including the current month that would be a full seasonal cycle.
2. Second a list is created of articles that are already planned for production i.e. the eligible list. Articles that have enough anticipation stock to satisfy future demand are removed from the list. If there are no articles in the list but there is time available for production and a future shortage an article needs to be setup and added to the list. This is done by evoking Procedure Anticipate Select.
3. The article with the lowest marginal increase in costs in the list is selected for production. As long as there is time available for production and an expected shortage the procedure is repeated.

7.4.3 Detailed Description

7.4.3.1 Notation

$RS(j)$:	The expected shortage for the horizon (t^*+1, j)
$R_{LY}(j)$:	The expected resources needed in the horizon (t^*+1, j) based on last year's demand
$\hat{x}_{ta}$:	Demand for article a in period t based on last year's demand (units)
$\hat{b}_{ta}$:	Binary variable taking value 1 if article a is demanded in period t from last year, and 0 otherwise
$\hat{d}_{tg}$:	Binary variable taking value 1 if an article from routing group g is demanded in period t from last year, and 0 otherwise
$AC(a,j,z)$:	Additional cost of holding an extra step size z of article a until period j
$MP(a,j,z)$:	Additional profit if we keep an extra step size z of article a until period j
$E(\quad)$:	Denotes an expected value

$$R_{LY}(j) = \sum_{a=1}^{N} \sum_{t=t^*+1}^{j} r_a \hat{x}_{ta} + k \sum_{a=1}^{N} \sum_{t=t^*+1}^{j} \hat{b}_{ta} + l \sum_{g=1}^{Q} \sum_{t=t^*+1}^{j} \hat{d}_{tg} \tag{7.10}$$

$$RS(j) = R_{LY}(j) - \sum_{t=t^*+1}^{j} R_t - \sum_{a=1}^{N} r_a\left(S_{t^*a} - S_{t^*a}^{\infty}\right) \tag{7.11}$$

$$S_{ja} = \max\left(0, S_{t^*a} - \sum_{t=t^*}^{j-1} E(x_{at})\right) \tag{7.12}$$

$$AC(a,j,z) = h_a (j - t^*)\, {}^{z}/_{r_a} \tag{7.13}$$

$$MP(a,j,z) = \left((v_a - c_a) + \pi_a\right) {}^{z}/_{r_a} - \left(h_a + (v_a - c_a) + \pi_a\right) {}^{z}/_{r_a}\, \Phi\left(S_{ja} + {}^{z}/_{r_a}\right) \tag{7.14}$$

Equation 7.10 resembles equation 7.4 and calculates last year's demand for capacity. If an article was demanded in a period in the last year in a period we assume it required at the most one setup.

Equation 7.11 calculates the expected resource shortfall. In the ideal case this is based on the order book in the future period, because the demand is however 'unknown' we will estimate $RS(j)$ based on last year's demand $R_{LY}(j)$. As denoted by the last term, the stock already built up is subtracted. Note that we assume all stock already built up to be usable in the future period.

Equation 7.12 calculates the expected produce up to level in period j based on the produce up to level of the current period and the expected demand in the mean time. Because we assume lost sales the minimum value is zero.

Equation 7.13 calculates the additional holding costs in the horizon until period j. The explanation for equation 7.14 is equal to explanation for equation 7.8.

7.4.3.2 Steps

Step AN1: Consider each time period within the horizon. We start with the next period : $j \in 2 \ldots 12, j = 2$

Step AN2: Calculate the (expected) future cumulative shortage and the amount of surplus capacity in the current period: $RS(j),\ R^+$

Step AN3: Without cumulative shortage or surplus in the current period we cannot continue. If $RS(j) < 0$ go to Step AN11 if $R^+ < 0$ END.

Step AN4: If we can continue create a list of products eligible to produce in the current time period: $L_{t^*} = \{\forall a \in A | S_{t^*a} > i_{t^*a}\}$

Step AN5: If there is enough inventory built up in the current period to reach the optimal inventory in the future period the article is removed from the list. If $S_{ja} > S_{ja}^{\infty}$ then $L_{t^*} = L_{t^*} - \{a\}$

Step AN6: We calculate the additional profit and cost for each article. Articles for which the profit is smaller than the additional cost are removed from the list. If $MP(a,j,z) < AC(a,j,z)$ then $L_{t^*} = L_{t^*} - \{a\}$

Step AN7: If there are no articles in the eligible list we have to select an article to add to the list: If $|L_{t^*}| = 0$ go to Procedure Anticipate Select

Step AN8: If there are no articles that can be selected we cannot continue: If $|L_{t^*}| = 0$ go to Step AN11

Step AN9: Select the article with smallest additional cost: $a_{min} = \arg\min_{\mathrm{a} \in \mathrm{L_{t^*}}} \left(AC(a,j,z)\right)$

Step AN10: Produce an extra step size of the selected article: $S_{t^*a} = S_{t^*a} + \max\left({}^{z}/_{r_a}, S_{ja}^{\infty} - S_{ja}\right)$ return to Step AN3.

Step AN11: If not at the end of the planning horizon look one period further ahead: If $j < 12$ Then $j = j + 1$ and go to Step AN2 else END

7.4.4 Procedure Anticipate Select

Procedure Anticipate Select resembles Procedure Allocate Select it also selects an article to be setup next if the list of articles eligible to produce is empty. The article to be setup next is produced until enough anticipation stock is built up to satisfy the future demand.

The articles that can be selected have a produce up-to level in the current month insufficient to reach the optimal level in period j, the additional profits exceed the additional costs and the production threshold. The holding costs are incurred over the interval$\left[S_{ja}^{\infty} - S_{t^*a}^{\infty} + \sum_{t=t^*}^{j-1} E(x_{at})\right]$.The first terms denotes the increase (decrease) in the optimal level, the second term the expected demand until period j.

The Procedure therefore allows the selection of articles that are not demanded in period j. If we select such an article we assume that is replaced by an article that requires an equal amount of time to produce and has equal holding and penalty costs. The article that incurs the least holding costs per required time is selected and added to the list of articles eligible to produce.

7.4.4.1 Notation

$HC(a,t^*,j)$: Holding cost incurred per unit of production time for article a from the current time period t^* until future period j

$$HC(a,t^*,j) = \frac{\left(S_{ja}^{\infty} - S_{t^*a}^{\infty} + \sum_{t=t^*}^{j-1} E(x_{at})\right) h_a}{r_a\left(S_{ja}^{\infty} - S_{t^*a}^{\infty} + \sum_{t=t^*}^{j-1} E(x_{at})\right) + k + l\left(1 - d_{t^*g}\right)} \tag{7.15}$$

Equation 7.15 is a ratio: the numerator describes the holding costs the denominator the required time: the effective production time, a small setup and an optional large setup. The large setup is only needed if the routing group the article belongs to has not been setup.

Note that we do not consider the penalty costs in equation 7.15 and attempt to produce until the future optimal produce up-to level is within reach. We do not consider the penalty costs because the articles already reached the optimal produce up-to level in the current period. This makes it unlikely that extra penalty costs are avoided in the current period. Producing up to the future optimal level might be suboptimal in the short run. Dividing the anticipation stock over more articles however means more setups. In the longer run it does not matter how we store capacity.

7.4.4.2 Steps

Step AN_SE1: Create a list of articles that can be setup next. We only consider articles not already setup and that exceed the production threshold. If $b_{t^*a} = 0$ and $r_a\left(S_{ja}^{\infty} - i_{t^*a}\right) < u$. This leads to preliminary list. Hereafter we also check if the future month produce up-to level is not already sufficient to reach the optimal level and if the additional profits exceed the additional costs: If $S_{ja} < S_{ja}^{\infty}$ and $MP(a,j,z) > AC(a,j,z)$ the article is included in the list W_{t^*}.

Step AN_SE2: Calculate the holding cost / time ratio for all articles: $HC(a,t^*,j), \forall a \in W_{t^*}$

Step AN_SE3: Select the article with smallest holding cost / time ratio: $a_{min} = \arg\min_{\mathrm{a} \in \mathrm{L}_{t^*}} \left(HC(a, t^*, j) \right)$

Step AN_SE4: Add the article to eligible list: $L_{t^*} = L_{t^*} + \{a\}$

7.5 Conclusion

We have added setups to the dynamic programming model of (Ketzenberg, Metters and Semple 2006). Hereafter we added setups to their MA heuristic. In all procedures we attempted to avoid setups. If setups were unavoidable we select articles based on a penalty cost time ratio in Procedure Allocate. In Procedure Anticipate we used a holding cost time ratio. The heuristic (and the model) are however an approximation of the richness of the 'real' system. Especially the stocking of setups and the expected demand are not modeled in detailed. We will briefly elaborate on them. In the next chapter we will implement the heuristic in a tool.

7.5.1 Stocking Setups

In case Procedure Anticipate is evoked we built up anticipation stock only if there is an expected shortage. This is checked by using equation 7.11. The latter term in equation 7.11 denotes the anticipation stock already build up. It is possible (but not sure) that during the built up also a future setup is avoided; 'stocked'. We assume the setup is not stocked and therefore it is not present in the latter part of equation 7.11. It is however present in the first part of equation 7.11 the expected demand for capacity. See also equation 7.10. This means that we built up more anticipation stock then might be necessary.

7.5.2 Expected Demand

In the original MA heuristic the demand distribution for each article and period is known in advance. This allows (Ketzenberg, Metters and Semple 2006) to calculate the expected surplus (shortage) in capacity in each month. In the problem on hand the demand distribution is based on the order book that is filled during the year. We therefore have only detailed demand information in the short term. We use a demand forecast to calculate the (surplus) shortage in capacity in each month. The forecasted demand is based on last year's demand. The aggregate demand for can vary relative to the same month last year. This can be incorporated in the heuristic. E.g. in case the demand for capacity in October can be 3% higher than last year. We can adjust the expected values for October 3% upwards. Because e.g. equation 7.10 and 7.12 consider the cumulative expected demand over several months this should be done with care. Adjusting the value upwards by 3% for 3 consecutive months can lead to 9% more anticipation stock. Also note that that we might already have more anticipation stock because we assume setups are not stocked.

8 Software Implementation

In this chapter we will discuss the implementation of the heuristic in Microsoft® Office Excel® 2003 hereafter referred to as the tool. We will first give the reason for selecting Excel®. Second we will elaborate on the implementation process.

8.1 Software Selection

SVI has licenses to use Microsoft® Office Excel® 2003, a spreadsheet program. We therefore investigated whether the heuristic could be implemented in Excel® 2003. The heuristic consists of a set of steps that are evoked depending on the outcome of several equations. The equations contain the most basic kind of mathematics; it concerns the operations of addition, subtraction and multiplication. The equations can be implemented in a spreadsheet program. The steps in the heuristic are specified once but repeated several times in succession. For reasons of usability it is necessary to automate these steps. The steps are automated by using Visual Basic for Applications (VBA). VBA is programming language than can be used to automate applications and is built into Excel®.

8.2 Implementation in Excel

Most equations are implemented using the basic spreadsheet functions in Excel®. Only the summations in equation 7.7 and 7.10 for the number of small and large setups are counted using VBA. We have developed Sub procedures in VBA for the MA Heuristic, Procedure Allocate, Procedure Allocate Select, Procedure Anticipate, Procedure Anticipate Select and a procedure to count the number of setups.

A Sub procedure is a series of VBA statements. A Sub procedure can take values from the spreadsheet, change values on the spreadsheets and evoke other Sub procedures. The (changed) values are the input for the equations. The VBA code for the Sub procedures can be found in Appendix H.

8.3 Summary

SVI has licenses to use Excel® 2003. We concluded that the heuristic can be implemented in Excel® 2003 by making use of the basic spreadsheet function and VBA. Hereafter we implemented the tool in Excel®. The tool will be subject to validation and verification in the next chapter.

9 Validation & Verification

Validation is ensuring that the tool can be used for the intended purpose i.e. the tool is applicable to the problem on-hand and the assumptions made. Verification is ensuring that the tool represents the conceptual description i.e. the tool ‘equals’ the MA Heuristic. We will use the modeling process of (Sargent 2005) as a guideline.

9.1 Modeling Process

We have described the problem on-hand and the assumptions made in chapter 6. Based on this description we have developed the MA heuristic in chapter 7. The implementation of the heuristic is described in chapter 8. See also Figure 9.1-1, based on (Sargent 2005). We will discuss the data validity in section 9.2, the computerized model verification in 9.3. In section 9.4 we will discuss the operational validity and the model validity.

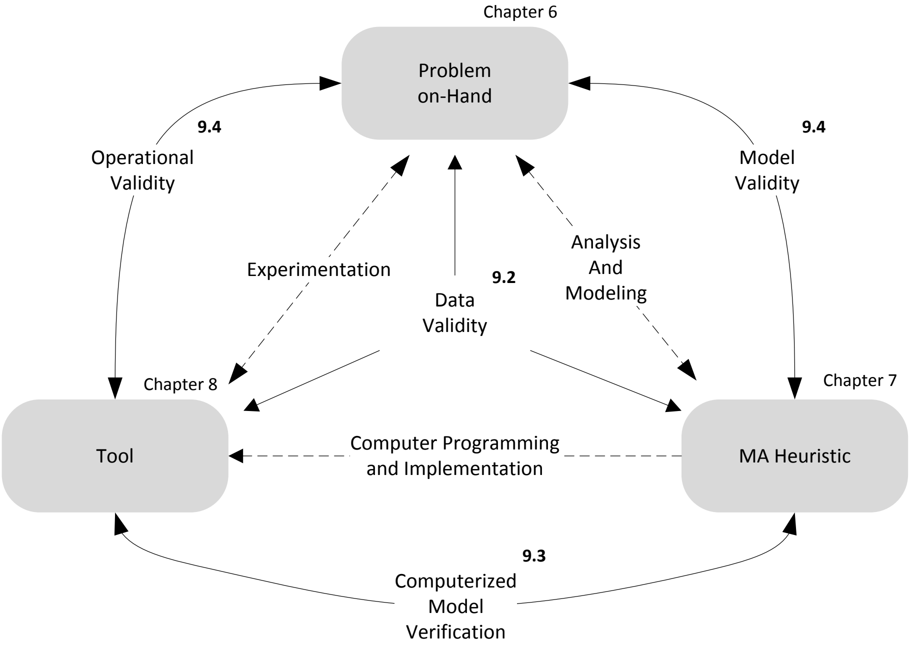


Figure 9.1-1 **“Modeling Process”**

9.2 Data Validity

The data necessary for building the tool, evaluate the tool and test the tool has to be adequate and correct (Sargent 2005). It is the responsibility of the user to check the input data for consistency, check for outliers and determine if they are correct. To avoid confusion on the origins of the data we used we have listed the input data, described the sources and explained the modifications made in Appendix I.

9.3 Computerized Model Verification

The purpose of the computerized model verification is to assure that the MA Heuristic is correctly implemented. The heuristic is implemented by using several Sub procedures. See also chapter 7 and Appendix H. We have verified the tool after the implementation of each Sub procedure. Therefore the verification of the heuristic did not take place at once. After the implementation of each procedure we checked whether the tool behaved as expected. If not we checked the VBA statements in the Sub procedure. When the number of VBA statements in a Sub procedure became larger we verified the working by inserting break points. At the break point the VBA code stops. A breakpoint is easily created or removed again.

In numerous occasions the tool did not behave as expected. After double checking if the heuristic of chapter 7 was implemented correctly also the heuristic was updated. E.g. in Step AL6 of Procedure Allocate the produce up to level is increased with the common step size. However this led to produce up-to levels higher than the desired produce up-to level. Therefore in the final version the maximum number of items than can be added depends on the step size and the difference to the desired produce up-to level

9.4 Operational and Model Validity

Model validation is ensuring that assumption made are correct and the MA heuristic ‘represent’ reality in a sufficient degree such that the model can be used for the intended purpose (Sargent 2005). Operational validity is ensuring that the tool can be used for the intended purpose. The purpose of the tool was to determine the optimal production quantities for each article given the inputs (holding costs, production costs, expected demand etc.).

The MA heuristic is too complex to validate manually. We can only validate the MA heuristic via the (verified) implementation of the MA heuristic: the tool. We cannot test for every possible situation that can occur. We will therefore do some extreme value and sanity tests as proposed by (Sargent 2005). We assess whether the tool behaves as expected. E.g. what will happen in case of zero holding costs? What will happen in case of extreme available capacity? The extreme values will give insight in the behavior of the tool.

There are over 600 articles produced on the M1 in Tiel each with different holding costs, production costs etc. It would be too complex to consider all articles, actual start-on hand stock, a full seasonal cycle etc. We will therefore test the validity of the model based on a limited test set of articles. Note that the purpose of this chapter is to test the general applicability of the MA heuristic, not only the applicability to the M1 in Tiel. We describe the test data in the next section hereafter we will describe the results of the extreme value and sanity tests.

9.4.1 Test Data

Table 9.4-1 depicts the articles, article routing group, production rate (r), revenue (v), production cost (c), holding cost (h) and start inventory (i_1). The last four columns depict the lower and upper limit of demand for the current and next period. Note the in the problem on-hand the lower limit is the quantity due in the order book. The upper limit needs to be estimated by Sales and Marketing.

Based on the lower and upper limit and the demand distribution function we use (see also Appendix G) the tool calculates the optimal produce up-to level and the expected demand. They are depicted in Table 9.4-2. Note that the optimal and expected demand are somewhere between the lower and upper limit.

Table 9.4-3 depicts the small setup time (k), the large setup time in excess of the small setup time (l), the step size (z) and the production threshold (u). The time available for production in the current and next period and the last row depicts the expected demand for capacity in the last period. Note that latter two rows result in an expected shortage for the second period if no stock is built up (see also equation 7.11).

Article	Routing	r	v	c	h	i_1	x_1^-	x_1^+	x_2^-	x_2^+
A	RG1	2	€ 10,00	€ 3,00	€ 0,75	10	50	120	60	130
B	RG1	2	€ 15,00	€ 4,00	€ 1,00	60	50	100	40	90
C	RG2	3	€ 20,00	€ 5,00	€ 1,25	20	40	60	30	50
D	RG2	3	€ 35,00	€ 8,00	€ 2,00	0	30	30	20	20
E	RG3	5	€ 80,00	€ 15,00	€ 3,75	0	10	10	0	0

Table 9.4-1 **“Article Test Set”**

Article	S_1^∞	S_2^∞	$E(x_1)$	$E(x_2)$
A	98	108	73	83
B	86	76	67	57
C	54	44	47	37
D	30	20	30	20
E	20	0	10	0

Table 9.4-2 **“Produce up-to Level & Expect Demand”**

k	10
l	20
z	1
u	10
R_1	800
R_2	800
$R_{LY}(2)$	1000

Table 9.4-3 **“Parameter Setting”**

9.4.2 Zero Demand

In case the lower and upper limit of demand are set to zero for all periods the tool does not produce. Also the optimal produce up-to level and expected demand are set to zero. The tool does attempt to select an article to be setup in Procedure Anticipate Select but is unable to do so.

9.4.3 Extreme Demand

In case of extreme demand i.e. the lower and upper limit equal to the 10 times the ‘normal demand’ the tool is not able to reach all the quantities due in the order book and Procedure Allocate is evoked. 100 units of article E are produced (consuming 500 units of time) and 80 units of article D are produced (consuming 240 units of time). After setups all the available time for production is used (800). This is line with the expected behavior. Article E is setup first that article avoids the most penalty costs per required time. If an article is setup by Procedure Allocate Select it is produced up-to the lower limit. Hereafter article D is produced until the time available for production is used.

9.4.4 Zero Available Time for Production

The tool does not produce.

9.4.5 Extreme Available Time for Production

In case of extreme available time for production i.e. 10 times ‘normal’ the tool is able to reach all the optimal produce up-to levels in each period. Because there is no future expected shortage also Procedure Anticipate is not run.

9.4.6 Zero Holding Cost

In case of zero holding costs the tool sets the optimal produce up-to level equal to upper limit; the maximal possible demand value. See also Table 9.4-4. All the optimal produce up-to levels are within reach and anticipation stock is built up.

If we set the available time for production for the current period to 10 times the ‘normal’ value (8000) the tool does build up anticipation stock beyond the expected future shortage. This is because there is an explicit check in Procedure Anticipate that only allows production in case of a future expected shortage; see also equation 7.11.

Article	x_1^+	x_2^+	S_1^∞	S_2^∞
A	120	130	120	130
B	100	90	100	90
C	60	50	60	50
D	30	20	30	20
E	10	0	10	0

Table 9.4-4 **“Zero Holding Cost: Produce up-to Level”**

9.4.7 Extreme Holding Cost

In case of extreme holding costs i.e. 10 times the normal holding costs the produce up-to levels are lowered. All the optimal produce up-to levels are within reach and Procedure Anticipate is evoked. The tool is still able to build up anticipation stock. However not the entire expected future shortage is produced in the current period despite a capacity surplus in the current period. This is in line with the expected behavior. Stock in only built up in case the additional holding costs exceed the future (expected) profit.

Article	S_1^∞	S_2^∞
A	70	80
B	65	55
C	47	37
D	30	20
E	10	0

Table 9.4-5 **“Extreme Holding Cost: Produce up-to Level”**

9.4.8 Zero Penalty Cost

In case the production cost for an article equal the revenue the loss profit penalty cost is zero. The optimal produce up-to level is set equal to the lower limit; the minimum possible demand value. If the lower limit is within reach the tool will produce up-to the lower limit. If the lower limit is not within reach Procedure Allocate is run. In that case the tool is unable to select an article to be setup because no penalty costs can be avoided. In the ‘reality’ we would not produce at al. We however do not consider the tool to be in error because we assume penalty costs to be higher than zero.

9.4.9 Extreme Penalty Cost

In case of extreme penalty costs i.e. production costs 10 times lower. The optimal produce-up-to levels approach the upper limit; the maximal possible demand value.

9.4.10 Conclusion

Because the tool acts in line with the expected behavior we conclude the MA heuristic and tool to be valid.

9.5 Summary

The data validity is the responsibility of the end user. To avoid confusion on the input data we used we have described it in Appendix I. We have verified that the MA heuristic has been implemented correct in section 9.3. We cannot manually validate the MA heuristic. We therefore validated the MA heuristic via the tool. The tool and MA heuristic have been validated in section 9.4. This is done with some extreme value and sanity tests. During the tests the tool behaved as expected. We conclude the MA heuristic and tool to be valid.

Although we had to, validating the MA heuristic and tool in one step is a risk. E.g. the MA heuristic is not valid because in a given formula we failed to include a minus sign. The tool is not correctly implemented because we did include the minus sign in the given formula. During testing the tool behaved as expected and we arrive at the wrong conclusion that the MA heuristic is valid.

10 Scenario Analysis

In this chapter we will analyze the effect of changes in input data on output data. First, we will present a scenario analysis framework. Second, we are interested if the tool can be used to improve the performance i.e. decreasing the holding and penalty costs at the M1 in Tiel. We do not have the actual past input data. We do not have the actual past output data. This means that we cannot determine with certainty that the MA heuristic is an improvement. We attempt to make it plausible by considering scenarios that resemble the possible past input data. Third, we are interested how the MA heuristic performs if we consider scenarios not directly related to the M1. The actual results of the scenarios can be found in Appendix J. In the last section we will, based on these results, extract some specific insights for the M1 located in Tiel and some general insights.

10.1 Framework

The output data and input data are depicted in Figure 10.1-1. We will first explain what output data we are interested in. Second, we will explain what input data we will change and why.

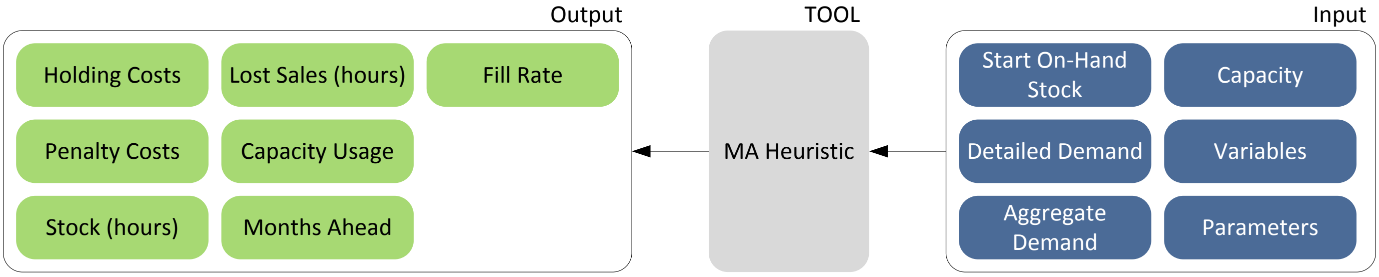


Figure 10.1-1 **"Scenario Analysis Framework"**

10.1.1 Output Data

We are interested in the on-hand stock at the end of each month. This determines the holding costs. We are also interested in the number of hours stocked. This allows us to investigate the building of stock.

In the current situation the production planner does not consider the holding costs when selecting articles for building stock or production in general. The current production strategy is aimed at minimizing setups by combining orders, not minimizing holding cost. In general MTO articles are cheaper to stock than MTS articles because MTO production costs are on average higher. The heuristic does attempt to minimize holding costs. We therefore expect a shift in the building of stock towards MTS articles. To investigate this shift we distinguish between MTO and MTS on-hand stock. We will also present the holding costs in a graph. We will also present the hours of effective production time stocked in a graph.

We incur penalty costs in case the produce up-to level is not high 'enough' to satisfy all demand. The heuristic assumes lost sales. This means that the penalty costs equal lost profit. We will present the penalty costs in the same graph as the holding cost.

In case of lost sales we are interested in the number of hours short. E.g. in case the shortage is only 8 hours it is possible to balance it with some overtime. In case the shortage is 60 hours the shortage cannot be balanced with (some) overtime. Note that overtime is not in our heuristic but it is in the toolbox of the operational planners. We will present the hours of lost sales in a table.

We are also interested how the available time for production is used. We distinguish time unused, effective production time, time spent on small setups and time spent on large setups. E.g. using more time for setups than in the current situation might be an explanation for high penalty costs.

In case of a capacity surplus in the current month Procedure Anticipate is evoked. There is capacity surplus if the optimal produce up-to levels in the current months are within reach. Procedure Anticipate attempts to anticipate to the expected future shortage by building stock. It starts by looking one month ahead. If there is no expected shortage, the number of months that is looked ahead is increased with one month until we have reached the end of the planning horizon (one year). We are interested in how many months that are looked ahead. We expect that we can look further ahead in the off-peak season then in peak season. E.g. if we can only look one month ahead in the off-peak season the optimal produce up-to levels might be too high.

In Chapter 3 we have defined fill rate i.e. the fraction of customer demand that is met without backorders or lost sales. Based on the actual demand in each month and the produce up-to level reached we are able to calculate the fill rate. Because of the large number of articles (ca. 600) we cannot present them in a convenient format.

10.1.2 Input Data

Demand

We have on-hand stock data at the end of each month from February 2007 until December 2008. Together with the production data in 2007 and 2008 we can calculate the actual demand from March 2007 until December 2008. The origins of the data used can be found in Appendix I. To give an impression of the seasonal pattern we have made Figure 10.1-2. It shows the effective production time (hours) needed to fulfill actual demand.

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Figure 10.1-2 **“Demand, Effective Production Time”**

Start On-hand Stock

The start on-hand stock used by the MA heuristic is based on the actual on-hand stock at the end of February 2007. This level might deviate from the optimal level. We interested in the working of our heuristic not in the past sub optimal decisions. We will therefore set the start on-hand stock to zero in case an article is not demanded from March 2007 until December 2008. This still does not guarantee an optimal level. We however consider almost two seasonal cycles and assume the remaining deviations from the optimal level to be mitigated over time. In case these deviations are not mitigated this is not a problem. It makes our output more realistic. E.g. equal to the current situation, the MA heuristic cannot prevent a customer from cancelling an order after production.

Detailed Demand

We need to have detailed demand information in the short term. This can be based on 1) the order book 2) on a judgmental forecast made by Sales and Marketing on a limited set of (MTS) articles. The project manager stated that the quoted lead time is ca. 8 weeks. We therefore assume the order book is known 2 months in advance. This means that, although we have actual demand from March 2007 until December 2008, we can only do a scenario analysis from March 2007 until November 2008. Yearly comparison will be made based on July 2007 until June 2008.

We are also interested in what happens if we have only detailed demand information for 1 month. If e.g. the holding and penalty costs show only a moderate increase, SVI can consider decreasing lead times.

If an article is MTO, actual demand needs to be in the order book. We will not speculate on MTO demand. In the ideal situation the order book is accurate. In the current situation the order book is not accurate; actual demand can be lower and the customer is not likely to request timely delivery. This makes sense because we suspect customers to be on the safe side. They are likely to order more than they actually need. They are also likely to set the due date earlier than they will request delivery. We have no past order book information. This means we cannot calculate the inaccuracy of the MTO demand. Based on an estimate of the project manager we will investigate a reasonable inaccuracy i.e. the MTO orders are at 120% of the actual demand.

If an article is MTS, this article will have zero lead time. At SVI however not all customers need direct delivery. In those cases the customer can opt to order MTS articles forward. This means that MTS demand is in the order book. We have no past order book information. This means we cannot calculate how much of the actual MTS demand in a given month was in the order book at the start of that month. We will therefore investigate what happens if the percentage of MTS demand ordered forward is at 80% and 20% of the actual demand. These percentages are an estimate. The operational planner revealed that he based the MTS production quantities on the quantities due in the order book. This means that the percentage ordered forward is significant enough to consider it in the planning process. The percentage is not high enough to only consider the order book (it is merely based on). After consulting the project manager we estimate the percentage ordered forward to be at the most 80% and at the least 20%.

So far we have had a look at the order book. If an article is MTS, not all demand is in the order book. To show how our heuristic works we need a judgmental forecast on the maximum demand value for each MTS article: the upper limit. The upper limit is calculated by adding a markup to the lower limit. The lower limit is the MTS demand already in the order book. The markup is an estimate, which we will explain in the next section.

Upper Limit = (Lower Limit) + (Markup)

We have actual demand data from March 2007 until December 2008. We will do a scenario analysis from March 2007 until November 2008. It would give our heuristic an unfair advantage if we would base the markup on the actual demand information. This information is 'normally' not known on beforehand. We therefore decided to use the current safety stock levels as a starting point for the markup. Note that we are unaware of the method used to determine these safety stock levels. According to the project manager the current safety stock level is used as a re-order point. If the on-hand stock drops to the re-order point this is a signal to start production. It takes a given time for production is actually started. To avoid stock outs, the re-order point needs to be high 'enough' to fulfill demand until production is started. This means that the re-order point is the maximum demand in a given period. This means we can use it as an estimate to show the working of the MA heuristic.

Note that the tool allows a markup to be set for each article at each month. We will however not vary the markup across articles or months because that would that would complicate the analysis. We want to show the working of the MA heuristic. The determination of the optimal markup is outside the scope of this project. The markup we use is based on:

Markup = (Safety Stock Factor) * (Safety Stock)

To avoid stock outs it makes sense to increase the safety stock factor if the percentage of MTS demand ordered forward declines. In the scenario with 80% of the MTS demand ordered forward we will start by setting the safety stock factor to 1. In case of 20% ordered forward we will start with a factor of 2.

In the months for which we have no order book information, we have set the safety stock factor to 3. This means that the expected MTS demand in those months is equal to the safety stock level. (See also Appendix G.) We advise the user to not increase this factor too much because we are speculating on future demand. We are not sure if the expected MTS demand will materialize.

Aggregate Demand

In the months for which we have no order book information, we need to forecast the expected demand. This allows us calculate the expected shortage (surplus) in capacity in each future month. The forecast is the aggregate number of hours needed in each month. The aggregate number includes the effective time needed for production, the small setups and the large setups. The aggregate number is based on the actual demand for articles from July 2007 until June 2008. We e.g. assume that aggregate demand in July 2008 to be equal to July 2007.

The actual demand can be higher than the forecasted aggregate demand. We will investigate an increase in 3% for the actual demand, the forecasted aggregate demand levels will be kept at the original level. This is according to the project manger a reasonable increase. A further increase would justify the re-allocation of articles and a lesser increase would not be worth investigating.

The forecasted aggregate demand and the actual demand are based on the current seasonal pattern. To give some general insight in the working of the MA heuristic we will investigate a scenario with a heavier seasonal pattern. The total effective production time needed to fulfill demand is kept equal. See also Table 10.1-1, it depicts the percentage change and the effective time needed for production (hours).

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Table 10.1-1 **"Heavier Seasonal Pattern"**

Capacity

We only have detailed production data from 2008. We base the available time for production i.e. the time that can be spent on effective production, small setups and large setups on this data set. We have no detailed production data from 2007. We therefore assume e.g. the time available for production in April 2007 to be equal to April 2008.

Variables and Parameters

We identify revenue, production costs, holding costs, and production rate as article variables. The revenue and production cost variables are based on the actual levels in 2007 and 2008. The holding costs per month are 1,25% of the production costs. See also Chapter 7. The production rate is based on the detailed production data from 2008. Because we have no indication that the used levels vary from the actual levels we will not investigate any variations.

We identify the production threshold and the step size as parameters. The production threshold is set to 1 hour. See also Chapter 7. The step size is also set to 1 hour. Depending on the steps that are evoked it takes 1 to 5 minutes to calculate the produce up-to levels for one month. The heuristic is run on a PC with an Intel® Core™ Duo CPU T 7500 @ 2.20 GHz and 2 GB of RAM.

The larger the step size the faster the heuristic; it takes e.g. less steps to allocate the capacity. A larger step size is also less accurate. One hour seems accurate enough given the small setup time (ca. 19 minutes) and large setup time (ca. 47 minutes) and the available capacity per month (ca. 320 hours; 4 weeks, 80 hours). Because the parameter setting seems reasonable we will not investigate any variations.

Summary

In this section we will summarize the scenarios we are going to investigate. In scenarios 1 to 4, we will vary the detailed demand information. The lower limit is the demand in the order book. E.g. 80% MTS ordered forward means the 80% of actual MTS demand was in the order book at the start of the month. In scenario 6 ($^+$) we increase the actual demand levels by 3%. In scenario 7 (*) we increase the actual and aggregate demand levels by the percentages in Table 10.1-1. The capacity, variables and parameters are not changed.

	Lower Limit known in advance	Lower Limit MTS ordered forward	Lower Limit MTO accuracy	Upper Limit markup
Scenario 1	2 months	80%	100%	1 * Safety Stock
Scenario 2	2 months	20%	100%	2 * Safety Stock
Scenario 3	2 months	80%	120%	1 * Safety Stock
Scenario 4	2 months	20%	120%	2 * Safety Stock
Scenario 5	1 months	80%	100%	1 * Safety Stock
Scenario 6$^+$	2 months	80%	100%	1 * Safety Stock
Scenario 7*	2 months	80%	100%	1 * Safety Stock

Table 10.1-2 **"Scenarios"**

10.2 Insights

Scenarios 1 to 4 resemble the (possible) current situation at SVI and are used to investigate the applicability of the tool for the M1 in Tiel. Scenarios 5 to 7 are used to investigate the general applicability. Based on our investigation we will first give insights for the M1 in Tiel and second some general insights. In the previous section we discussed the outputs we were interested in. The outputs for scenarios 1 to 7 and the current situation (before the implementation of the redesign) can be found in Appendix J.

10.2.1 Insights for the M1 in Tiel

In the literature there is a distinction between pre-tests and post-tests. A pre-test is the measurement of outputs before a redesign. A post-test is the measurement of outputs after the implementation of a redesign (Aken, Berends and Bij 2004). The pre-test, for scenarios 1 to 4, is the actual output in the current situation (before the implementation of a redesign). For some outputs we can only do a post-test because we have no pre-test measurement. We will first present the pre-test – post test.

10.2.1.1 Pre-test – Post-test

We have on-hand stock data from February 2007 until December 2008 and the capacity usage in 2008 (see also Chapter 5). This allows us to do a pre-test – post-test on the holding cost, the stock in hours and the capacity usage.

See Table 10.2-1 for the holding costs. In all scenarios the holding costs are decreased significantly. The values however should be interpreted with care. We do not have the actual input data used in the current situation. We therefore attempted to resemble the current situation. This makes the decrease in holding costs plausible but not certain.

The holding costs in scenario 1 are the smallest and in scenario 4 the largest. This makes sense. In scenario 1 we know 80% of actual MTS demand in advance and MTO demand in the order book is 100% accurate. In scenario 4 we know only 20% of actual MTS demand in advance and the MTO demand is at 120% of the actual level. See also Table 10.2-1.

In scenario 1 the accuracy of MTO demand is 100%, in scenario 3 120%, the other detailed demand information remains equal. The MTO holding costs are in scenario 3 are roughly 200% of scenario 1. In scenario 2 the accuracy of MTO demand is 100%, in scenario 4 120%, the other detailed demand information is equal. The MTO holding costs are in scenario 4 are roughly 200% of scenario 2. Without a thorough investigation we arrive at the preliminary conclusion that an inaccuracy in the order book leads to disproportional MTO holding cost (+20% vs. +100%). We presume that this is caused by low stock turnover i.e. dead stock on the vain produced MTO articles. Over time the low accuracy leads to the accumulation of dead stock.

The heuristic considers stock above the current month optimal level to be part of the anticipation stock. It also assumes this stock to be usable in a future month (see also equation 7.11). This is assumption is false in case of 'dead stock'. The 'dead stock' cannot be used in a future month because it is likely there is no demand on the 'dead stock' articles. This might mean that not enough capacity is stored. This might lead to capacity problems in the peak periods. Note that the problem does not need to surface until the peak period because the tool makes a false assumption. When it does surface there might be insufficient time to find a solution. This means that the capacity problem needs to be solved ad-hoc.

The 'dead stock effect' is only partially reflected by the on-hand stock used to compare the scenarios with: the current situation. We make use of a machine multiple that is altered each half year. It is likely that the 'dead stock' articles were not produced on the M1 the next half year. This means that the machine multiple is zero. If the machine multiple is zero we no longer take the 'dead stock' into account. This means that the holding costs in the current situation are likely to be higher than € <<confidential>>. See Appendix I for the use of the machine multiple.

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Table 10.2-1 **"M1: Holding Costs"**

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Table 10.2-2 **"M1: Stock (hours)"**

See Table 10.2-2 for the number of hours stocked. In all scenarios the number of hours stocked declines. This is again in line with the percentage of MTS demand known in advance and the accuracy of MTO demand. Comparing Table 10.2-1 and Table 10.2-2 reveals that the decrease in holding costs is larger than the decrease in number of hours stocked. E.g. In scenario 4 the decrease in holding cost is 45% the decrease in number of hours 29%. This is in line with expectations. The MA heuristics stores capacity at the least possible holding costs.

See Figure 10.2-1 for the capacity usage. The corrective maintenance and various delays are not in the MA heuristic and therefore equal to the current situation. The time that is spent on effective production or remains unused, is in scenario 1 to 4 roughly at <<confidential>>% of the available capacity. First, this means that the total time spent on setups in not increased. Second, the production planning proposed by the heuristic is sustainable. No (possible) effective production time is lost. Third, the decline in inventory holding costs is not explained by a decrease in the time spent on effective production.

The time lost on small setups increases in scenario 1 to 4, compared to the current situation (ca. <<confidential>>% vs. <<confidential>>%). This is in part explained by the machine multiple. Recall that we used a machine multiple to arrive at the demand for the M1. E.g. consider an article that is produced in equal quantities on both the M1 and M2. This will give a M1 multiple of 50% i.e. 50% of each order is allocated to the M1. In practice the total order is produced either on the M1 or the M2 with a probability of 50%. This explains why the number of (small) setups is the current situation is smaller.

The time lost on large setups decreases in scenario 1 to 4, compared to the current situation (ca. <<confidential>>% vs. <<confidential>>%). This is in line with the expected behavior. The heuristic attempts to avoid setups. E.g. it attempts to avoid setups by allowing at the most one large setup per routing group per month.

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Figure 10.2-1 **“M1: Capacity Usage”**

10.2.1.2 Post-test

We have no data on the penalty costs, the lost sales (hours), the number of months that is looked ahead i.e. lead or the number of hours not used for production in the current situation. We can therefore only do a post-test.

See Table 10.2-3 for the lost sales penalty costs. The penalty costs should be interpreted with care. The heuristic decides based on the inputs at the start of the month. It does not react to the actual demand that materializes on a day-to-day basis. It does not learn from past stock outs. In ‘reality’ the production planner has many options to intervene and avoid penalty costs. E.g. revise production quantities downwards for some articles and upwards for articles almost out of stock or expedite production runs planned for the next month.

See Table 10.2-4 for the lead. The MA heuristic only looks ahead if the current period produce up-to levels are reached. In scenario 1 and 3 we use a safety stock factor of 1 and the median lead is 6 and 7. In scenario 2 and 4 we use a safety stock factor of 2 and the median lead is 11 and 11,5. We conclude that given the percentage MTS demand ordered forward for scenarios 1 and 3 (80%), this means that the safety stock factor is likely set too high. The penalty costs in scenario 1 and 3 are roughly equal. This is also the cast for scenarios 2 and 4. This means that the despite the too high safety stock factor no penalty costs are avoided. We presume that the larger part of the penalty costs are caused by a limited set of articles.

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Table 10.2-3 **“M1: Penalty Costs & Lost Sales (hours)”**

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Table 10.2-4 **“M1: Lead & Not Used (hours)”**

10.2.2 General Insights

Scenarios 5-7 are used to arrive at some general insights, not necessarily the improvement potential compared to the current situation. Because scenarios 5-7 do not resemble the current situation at SVI we will not use a pre-test – post-test. We will compare the outputs of scenarios 5-7 to scenario 1. It allows us to focus on the changes because of the different inputs instead of the changes because the heuristic has been implemented. We will first present the test results using tables and figures. Hereafter we will arrive at some general insights.

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Table 10.2-5 **"Holding Costs"**

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Table 10.2-6 **"Stock (hours)"**

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Figure 10.2-2 **"Capacity Usage"**

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Table 10.2-7 **"Penalty Costs & Lost Sales (hours)"**

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Table 10.2-8 **"Lead & Not Used (hours)"**

10.2.2.1 Insights

In scenario 5, compared to scenario 1, the time the order book is known in advance is decreased from 2 months to 1 month. We do not speculate on MTO demand. This means the MA heuristic cannot build stock in MTO articles and we should arrive at zero MTO holding costs. In scenario 5, we have however € <<confidential>>in MTO holding cost. These costs are explained by the MTO stock ('dead stock') already in the start on-hand stock. In scenario 1, we have € <<confidential>>in MTO holding cost; a modest increase. First, we conclude that he tool is not keen in building stock using MTO articles. Second, the extra month of detailed MTO demand information is not used by the MA heuristic in scenario 1. This is in line with expectations because the MA heuristic selects articles based on holding costs and MTO articles are in general more expensive.

In scenario 5, compared to scenario 1, the penalty costs are roughly doubled. This is in line with expectations. The time the order book is known in advance is decreased. In scenario 1 and 5, 80% of the actual MTS demand is in the order book. The extra month of detailed demand information allows the tool to select articles for building stock that are most likely demanded.

In scenario 5, compared to scenario 1, more setups are necessary (<<confidential>>% vs. <<confidential>> %). This is in line with expectations. The tool is to a lesser extent able to build stock in articles that are most likely demanded. This results in extra setups.

In scenario 6, compared to scenario 1 the actual demand, is increased by 3%. The penalty costs and hours lost sales increase significantly. This is in line with expectations. Demand is higher at equal capacity. The number of hours lost sales is <<confidential>> hours in total. We are therefore unsure whether the penalty costs can be avoided by interventions of the operational planner.

Scenario 7 has, compared to scenario 1, a heavier seasonal pattern. The holding cost increase significantly. This is in line with expectations, more anticipation stock needs to build up. The penalty costs show a moderate increase (€<<confidential>> vs. € <<confidential>>). Most penalty costs are incurred at the seasonal peak (see also Appendix J). This means that the production planner has fewer options to intervene. We therefore are not sure whether the penalty costs can be avoided.

11 Implementation at SVI

In the previous chapter we did a scenario analysis. In scenario 1 to 4 we attempted to resemble the current situation at SVI. The results of scenarios 1 to 4 make it plausible, but not certain, that the costs can be decreased. This means that it is likely that the tool is applicable to the current situation at SVI. In this chapter we will discuss how and by whom the tool can be used.

11.1 Tactical Planner

In the current situation the tactical planner has a coordination task. The tactical planner coordinates the capacity between machines and locations. The tactical planner also coordinates between the operational planners and Sales. The operational planners decide on the production quantities. Sales generates orders and accepts commitments on the due dates.

Consider the following example of the coordination task. Production planners realize that the quantities due in the order book are not within reach. They contact the tactical planner. First, the tactical planner attempts to solve the 'problem' by re-allocating orders. Some articles from the high utilization machine are reallocated to an identical low utilization machine at another location. Second, the tactical planner can contact Sales. Sales will then attempt to influence the due dates. This is called sales flexibility (Bertrand and Wijngaard 1986).

The 'real problem' in the current situation is that capacity problems come unnoticed. This means that capacity problems need to be solved quickly and solutions are picked ad-hoc. The tactical planner can use the tool for **scenario analysis** as we did in the previous chapter. The tool outputs (e.g. number of hours lost sales) can help to signal potential capacity problems further in advance then in the current situation. This means that the capacity problems can be avoided or solved in a structured way.

We have run the heuristic on a PC with an Intel® Core™ Duo CPU T 7500 @ 2.20 GHz and 2 GB of RAM. It takes 1 to 5 minutes to calculate the optimal produce up-to levels for a single month. This allows the tactical planner to generate outputs up to the peak period or for a full seasonal cycle (12 months) within one hour. To facilitate the use of the tool, in which we implemented the MA heuristic, we have developed a second Microsoft® Office Excel® 2003 tool. This tool helps to insert input data and extract output data.

Given the limited run time (one hour for 12 months), the tool can be used for scenario analysis on a regular basis. However in the short term (<2 months) it might be unclear whether certain changes are temporal or structural. A temporal variation should 'normally' be handled at the operational level. Therefore we recommend SVI to use the tool for evaluation purposes every 2 months. However if a temporal variation is not 'normal' this might be a motivation to use the tool already after one month. The 'normal' is based on the experience of the planners.

The outputs of the tool should be **interpreted** critically by the user. E.g. the holding costs, the penalty costs, the hours lost sales are expected values, not the final values. Before the values become final, the tactical planner and operational planner have many **options to intervene**. Note that the MA heuristic is only a model, a simplification of the real world. The user should be aware of the model limits. E.g. overtime is not in the model, reallocations are not in the model, sales flexibility is not in the model.

11.2 Operational Planner

In the current situation the operational planner decides on the production quantities. He decides based on 1) the order book 2) the on-hand stock. The production planner attempts to meet the due dates in the order book, avoid stock outs for MTS articles and maximize the effective production time. The production planner maximizes the time spent on effective production by minimizing the time spent on setups. An article needs to be setup because there is no-on hand stock and it is due in the order book. The operational planner will then look ahead in the order book and combines orders for the same article into one production run. There is no formal method in the current situation that helps to decide how far to look ahead in the order book, the current method is based on experience.

The MA heuristic also attempts to meet the due dates in the order book, avoid stock outs for MTS articles and maximize the effective production time. The MA heuristic attempts to maximize the time that can be spent on effective production by avoiding setups if possible. Based on the results for scenario 1 to 4 in the previous chapter the time spent on effective production is roughly equal to the current situation. The tool is based on a formal method. The advantage of the tool is that it also attempts to minimize holding costs and penalty costs, using a formal method. The results of scenarios 1 to 4 make it plausible (but not certain) that costs can be decreased.

Note again that the results should be **interpreted** critically by the user. The tool calculates the optimal produce up-to levels that should be reached at the end of the month. The tool does this based on the inputs at the start of the month. The tool does not decide when to produce an article during the month. The scheduling still needs to be done by the production planner. Actual demand materializes during the month on a day-to-day basis. Based on this new information the tool can be run again during the month to further optimize the outputs. Again the outputs should be interpreted with care. E.g. the tool proposes the produce an article because it is due in the order book. At the same time the operational planner does not expect the demand to materialize soon because that is typical for the customer the article is produced for. In those cases the **operational planner can still decide** to postpone production.

12 Conclusion & Recommendations

Throughout this project we have followed the regulative cycle. The last part of the regulative cycle is the evaluation. In this chapter we will evaluate the project from a practical perspective. We will arrive at conclusions and give some recommendations. In the next chapter we will evaluate the project from a scientific perspective.

12.1 Project Deliverables

At the start of this project we defined two deliverables: a mathematical model and a tool. We present the first deliverable, a dynamic programming model, in Chapter 7. The dynamic programming model can however not be used to determine the optimal production quantities for realistic problem sizes. We therefore developed the MA heuristic. The MA heuristic can be used for realistic problem size. We have implemented the MA heuristic in an Excel ® tool. The tool was subject to verification and validation in Chapter 9.

The purpose of the tool was twofold: determine the optimal production quantities in the current month and detect and quantify future capacity problems. The optimal production quantity minimizes holding and penalty costs in the current and future months. With regard to the first purpose: the tool calculates the optimal produce up-to levels first without considering capacity. When there is not enough capacity available in a period the tool allocates the available capacity. If there is enough capacity available the tool looks ahead and attempts to anticipate on future shortages by building up stock. The tool also takes the setup times into account. This means the produce up-to levels proposed by the tool should be in reach in reality.

With regard to the second purpose: the tool can be used for scenario analysis as we did in Chapter 10. Based on actual demand from last year's we can simulate the expected demand for the future months. The tool will e.g. calculate the expected penalty costs and number of hours sales lost in the future months.

We conclude that we have both delivered the mathematical model and tool that was asked for. With regard of the possible use of the tool at SVI we refer to Chapter 10. We will end this section by giving a list of the strengths and weaknesses of the tool.

Strengths

The tool:

- answers when to start the built up of anticipation stock.
- answers which articles to use for the building of stock.
- answers how to divide the capacity if we cannot satisfy all demand.
- takes setup times into account. This means that the produce up-to levels should be in reach.
- is usable for scenario analysis. The tactical planner can use the tool to investigate what-if scenarios. E.g. what happens if we would decrease the lead time?

Weaknesses

The tool:

- requires a large amount of input data. E.g. it requires detailed demand information, it requires on-hand stock levels, it requires aggregate demand information, it requires detailed cost information on each article and it requires production rates. In the current situation it might take a considerable amount of time to collect and modify the required input data.
- has limits. E.g. overtime is not in the model, reallocations are not in the model, sales flexibility is not in the model.
- the outputs of the tool are expected values, not final values. The results should be interpreted by the user.

12.2 Conclusion

The seasonal fluctuations in demand, the large number of articles, setups and the limited available capacity lead to a complex production planning problem. A problem that requires weeks of CPU time to solve optimally, even in the 4 article case. However the tactical planner and operational planner manage to solve it on a day-to-day to basis. In the current situation they solve it without the help of formal methods, but based on experience and common sense.

In this project we have attempted to decompose the production planning problem. We have reviewed the customer service objectives in Chapter 3. We have reviewed demand in Chapter 4. In Chapter 5 we have reviewed the capacity usage and machine characteristics. Based on the problem characteristics and the available literature we have developed the MA heuristic. The MA heuristic is implemented in a tool.

In Chapter 10 we did a scenario analysis. We attempted to resemble the current situation at SVI and use the tool to investigate the potential decrease in costs. The results make it plausible, but not certain, that the costs can be decreased. We can only conclude this with certainty, if we would have done the scenario analysis with the actual input data the operational planners have.

Although the potential of the tool remains unknown for know, we recommend the operational planner to use the tool. Compared to the current situation the tool uses a formal method to arrive at the produce up-to levels for each month. The solution might be suboptimal. However the production quantities in the current situation are also suboptimal (this is not a reproach but a logical consequence of the complexity of the problem). Note however that the production quantities of the tool should be seen as a first start. Although we have validated the tool in Chapter 9, errors can be made. Also note that the tool has limits. E.g. overtime is not in the model, reallocations are not in the model, sales flexibility is not in the model. This means that the production quantities calculated by the tool need to be interpreted. The operational planner does this based on his experience and common sense. In the end it is the operational planner that decides on the production quantities and not the tool. The production quantities can be based on the production quantities proposed by the tool.

The use of the tool at the operational level might avoid certain problems. Other problems (e.g. caused by structural higher demand) cannot be avoided by the use of the tool. In those cases the tactical planner can use the tool for scenario analysis. The tool might help to detect problems further in advance than in the current situation. This gives the tactical planner time to find a structural solution instead of solving the problem ad-hoc.

12.3 Recommendations

We will first give some general recommendations. Second, we will give some specific recommendations aimed at the input data needed for the tool. How and by whom tool can be used is explained in Chapter 11.

General Recommendations:

- We recommend SVI to measure customer service. In the current situation the magnitude of capacity problem e.g. the hours of capacity short, the penalty costs incurred, the fill rate, the delivery reliability and the hours of lost sales are not recorded. This means we cannot quantify the problem. Without quantification of the problem we do not know the relevance of the capacity problem. E.g. 100 hours of lost sales is more relevant than 1 hour of lost sales.
- In the current situation there is no formal method to arrive at the safety stock levels. In Chapter 4 we concluded that an exact analysis of time varying demand is too complicated for day-to-day use in practice. Based on however the realized customer service SVI can e.g. adjust the safety stock level up and downwards.

Specific Recommendations:

- We recommend SVI to collect historical data on the order book. In the current situation the order book is not accurate: actual demand can be lower and the customer is not likely to request timely delivery. We have no past order book data. This means we cannot calculate the inaccuracy of the order book. E.g. in Chapter 10, the scenario analysis, we used an estimate for the inaccuracy based on the experience of the project manager. Using the ‘actual’ inaccuracy ensures that the outputs of the scenario analysis better resemble reality.

  Part of the MTS demand is in the order book at the start of the month. We have no past order book data. This means we cannot calculate how much of the actual MTS demand realized at the end of the month, was already in the order book at the start of the month. The result, the percentage of MTS demand ordered forward, can be used as input for the tool. Using the ‘actual’ percentage ensures that the outputs better resemble reality.
- We recommend SVI to use a formal method to arrive at the maximal demand values for the MTS demand. Not all MTS demand is in the order book. Customers can request delivery with zero lead time. The maximal demand values are based on a judgmental forecast. This forecast can e.g. be adjusted based on the realized customer service.

13 Scientific Reflection

In this chapter we will evaluate the project from a scientific perspective. According to (Aken, Berends and Bij 2004) a single research project can contribute to existing literature in four ways; 1) Innovation i.e. a new theory or solution 2) Elaboration i.e. new application of an existing theory or solution 3) Verification i.e. the first successful application of a new theory or solution 4) Falsification i.e. the refutation of an existing theory or solution. In the next session we will argue that we innovated and to a lesser extent verified. In the last section we will give directions for future research.

13.1 Contribution to Literature

We have searched to available literature for articles that answer the questions: 1) when to start the built up of anticipation stock and 2) which articles to use for the building of stock 3) how to divide the capacity if we cannot satisfy all demand. Another criterion was that the key-features of the articles would preferable resemble the situation on-hand. We searched the available literature using the following combination(s) of key-words: multi-item (or multi-product), seasonal demand, setups, capacity, constraint and production. We used ABI/Inform and Google Scholar[1]. To the best of our knowledge there are no scientific articles that match all criteria. We therefore decided to focus and made combinations of the key words, but excluded setups from the list. Setups are an important part of the problem on-hand but not directly related to the three questions.

From the literature found we decided to use (Ketzenberg, Metters and Semple 2006) as a starting point. They developed a MA heuristic that 1) answered the three questions 2) is an improvement compared to other heuristics and 3) shows no signs of deterioration in performance as the number of articles increases. The disadvantage is that the MA heuristic (or any of the other heuristics) does not include setups.

We innovated because we added setups to the MA heuristic of (Ketzenberg, Metters and Semple 2006). The basic idea is equal to (Ketzenberg, Metters and Semple 2006). The adapted heuristics takes setup times into account in the capacity calculations and attempts to avoid setups if possible.

We attempted to verify the applicability of our adapted MA heuristic in Chapter 10. The results make it plausible, but not certain, that the costs can be decreased. But even if we would have been certain it is hard to conclude on the general applicability based on a single case study.

13.2 Future Research

To avoid setups we have introduced a production threshold to our adapted MA heuristic. An article is only setup if the time that an article can be produced is longer than the threshold. In this project we have set the production threshold to 1 hour. This was based on the experience of the project manager, the time needed for a large setup (ca. 46 minutes) and a small setup (ca. 18 minutes). The threshold of 1 hour might be suboptimal. We suggest investigating the determination of the optimal threshold level. This level might vary per article.

During the building of stock it might be possible that also a future setup is avoided. E.g. in January we produce all the quantities due for February. This means no setups are necessary in February. This means that by building stock also future setup are avoided; ‘stocked’. Our adapted MA heuristic does not take the possibly avoided setups into account. This means that in e.g. in January more anticipation stock is build than strictly necessary. We suggest investigating to which amount setups are avoided in a future period, by the building of stock in the current period.

---

[1] http://scholar.google.com

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15 Reading Guide

In this chapter the tables, figures, abbreviations, model variables, and definitions used throughout the report are listed.

15.1 Tables

Table 9.4-1 **“Article Test Set”** 39
Table 9.4-2 **“Produce up-to Level & Expect Demand”** 39
Table 9.4-3 **“Parameter Setting”** 39
Table 9.4-4 **“Zero Holding Cost: Produce up-to Level”** 40
Table 9.4-5 **“Extreme Holding Cost: Produce up-to Level”** 40
Table 10.1-1 **“Heavier Seasonal Pattern”** 44
Table 10.1-2 **“Scenarios”** 45
Table 10.2-1 **“M1: Holding Costs”** 46
Table 10.2-2 **“M1: Stock (hours)”** 46
Table 10.2-3 **“M1: Penalty Costs & Lost Sales (hours)”** 47
Table 10.2-4 **“M1: Lead & Not Used (hours)”** 47
Table 10.2-5 **“Holding Costs”** 48
Table 10.2-6 **“Stock (hours)”** 48
Table 10.2-7 **“Penalty Costs & Lost Sales (hours)”** 48
Table 10.2-8 **“Lead & Not Used (hours)”** 48

15.2 Figures

Figure 1.2-1 “**Group Structure”** 1
Figure 1.2-2 **“Supply Chain & Production Process”** 2
Figure 1.2-3 **“Competitive Forces Model”** 2
Figure 1.3-1 **“Market Attractiveness”** ....<<confidential>>
Figure 1.3-2 **“Product Families”** 4
Figure 2.2-1 **“BWW-framework”** 6
Figure 2.2-2 **“Paver Demand 2006 & 2007”** 7
Figure 3.1-1 **“Hierarchical Objectives”** 11
Figure 3.2-1 **“Customer Order Decoupling Point”** 12
Figure 4.1-1 **“Demand Forecasting Framework”** 15
Figure 4.2-1 **“Demand Planning Process”** 15
Figure 5.1-1 **“M1, Available Capacity & Usage”** 18
Figure 5.1-2 **“Routing Group”** 18
Figure 5.1-3 **“M1, Box plot Large Setups”** 19
Figure 5.1-4 **“M1, Box plot Small Setups”** 19
Figure 5.1-5 **“Corrective Maintenance”** 19
Figure 5.1-6 **“Various Delays”** 20
Figure 6.1-1 **“Cumulative Demand and Production”** 22
Figure 6.3-1 **“Basic Idea KMS”** 23
Figure 7.2-1 **“Flowchart MA Heuristic”** 30
Figure 9.1-1 **“Modeling Process”** 38
Figure 10.1-1 **“Scenario Analysis Framework”** 42
Figure 10.1-2 **“Demand, Effective Production Time”** 43
Figure 10.2-1 **“M1: Capacity Usage”** 47
Figure 10.2-2 **“Capacity Usage”** 48

15.3 Abbreviations

ca.	circa
CPU:	Central Processing Unit
CRH:	CRH Plc. (an Irish building material group)
CRH-IPB:	CRH Infrastructural Products Benelux (the Benelux branch of CRH)
EBIT:	Earnings Before Interest and Tax
e.g.	abbreviation for Latin exempli gratia, meaning 'for example'
etc.	Latin expressions, meaning 'and so on'
EMQ:	Economic Manufacturing Quantity
EU:	European Union
F&A:	Finance and Accounting
FGI:	Finished Goods Inventory
GHz:	Gigahertz
i.e.	abbreviation for Latin id est, meaning 'that is; in other words'
KMS	Used to cite (Ketzenberg, Metters and Semple 2006)
NMa:	Nederlandse Mededingsautoriteiten (Dutch competition regulator)
MA:	Marginal Analysis
MTO:	Make-to-Order
MTS:	Make-to-Stock
PC:	Personal Computer
RAM:	Random-access memory
RONA:	Return on Net Assets
RMI:	Raw Materials Inventory
SAP:	SAP AG (software enterprise best known for its Enterprise Resource Program: SAP ERP)
SCM:	Supply Chain Management
SVI:	Struyk Verwo Infra
VBA:	Visual Basic for Applications
Vs:	versus

15.4 Model Variables

A:	Set of articles, index $a, a \in \{1 \dots N\}$
A_g:	Subset of A, articles in routing group g
$AC(a, j, z)$:	Additional cost of holding an extra step size z of article a until period j
$AP(a, z)$:	Additional profit for an extra step size z of article a
b_{ta}:	Binary variable taking value 1 if article a is produced in period t, and 0 otherwise
$\hat{b}_{ta}$:	Binary variable taking value 1 if article a is demanded in period t from last year, and 0 otherwise
c_a:	Production cost per unit for article a
d_{tg}:	Binary variable taking value 1 if an article from routing group g is produced in period t, and 0 otherwise
$\hat{d}_{tg}$:	Binary variable taking value 1 if an article from routing group g is demanded in period t from last year, and 0 otherwise
$E(\quad)$:	Denotes an expected value
h_a:	Holding cost per period per unit of article a
$HC(a, t^*, j)$:	Holding cost incurred per unit of production time for article a from the current time period t^* until future period j
i_{ta}:	On-hand stock of article a before production, before demand in period t (units)

f_t:	Minimum expected total cost function for periods $t, t+1, \dots, T$
G_t:	Single-period holding and lost sales cost function
j:	Denotes a future time period
k:	Setup time required if no change of routing group is necessary (hours)
l:	Extra setup time required if a change of routing group is necessary (hours)
L_{t^*}:	Subset of A, denotes the articles eligible to produce in time the current time period t^*
m:	Arbitrary value for demand x.
$MP(a, j, z)$:	Additional profit if we keep an extra step size z of article a until period j
$PC(a, t^*)$:	Penalty cost avoided per unit of production time for article a in the current time period t^*
$Pr(\quad)$:	Denotes a probability
R_t:	Time available for production in period t
R^+:	Surplus capacity (capacity short) in period t^*
RG:	Set of routing groups, index $g, g \in \{1 \dots Q\}$
$RS(j)$:	The expected shortage for the horizon $(t^* + 1, j)$
$R_{LY}(j)$:	The expected resources needed in the horizon $(t^* + 1, j)$ based on last year's demand
r_a:	Capacity per unit required to produce article a (hours)
S_{at}:	Optimal produce up-to level of article a in period t, without considering the general capacity constraint (units)
S_{at}^{∞}:	Optimal produce up-to level of article a period t (units)
t^*:	Denotes the current time period $(t^* = 1)$
TP:	Set of time periods, index $t, t \in \{1 \dots T\}$
u:	Production threshold, the minimum amount of time an article needs to be produced to justify a setup (hours)
v_a:	Revenue per unit for article a
W_{t^*}:	Subset of A, denotes the articles that can be setup next in the current time period t^*
x_{ta}:	Demand for article a in period t (units)
$\hat{x}_{ta}$:	Demand for article a in period t based on last year's demand (units)
x_{ta}^{-}:	Demand for article a due in period t based on the order book (units)
x_{ta}^{+}:	Maximum demand for article a in period t based on the order book and a judgmental forecast (units)
y_{ta}:	Inventory of article a on-hand after production, but before demand in period t (units)
z:	Step size (hours)
π_a:	Lost sales penalty cost per period per unit in excess of lost profit for article a
$\phi_{ta}(x_{ta})$:	Probability density function for demand x_{ta}
$\Phi_{ta}(x_{ta})$:	Cumulative distribution function for demand x_{ta}
$(value)^+$:	Maximum $(0, value)$

15.5 Definitions

Available Capacity: The time the machine can be used
Available time for Production: (Available Time) – (Delays)
Backlog: In case on-hand stock does not allow a customer order to be satisfied directly and the customer is willing to wait there is a backlog
Cycle Time: The time between two consecutive production runs for the same article
Delays: The time that could have been used for production but is lost other than on setups e.g. corrective maintenance
Delivery Reliability: the fraction of customer orders ready for distribution at the due date
Due Date: The date when an order is agreed to be ready for distribution
Effective Production Time: (Available Time for Production) – (Setups)
Fill Rate: the fraction of customer demand that is met without backorders or lost sales. The optimal fraction balances the holding costs, the penalty costs and loss of contribution margin in case of lost sales
Inventory Position: (On hand) – (Backlog) – (Reserved) + (Scheduled Production)
Lead Time: The time between the placement of an order and the order being ready for distribution.
Lost Sales: In case on-hand stock does not allow a customer order to be satisfied directly and the customer is unwilling to wait sales are lost
Net Stock: (On hand) – (Backlog); it can become negative
On-hand Stock: Physical available stock; it can never be negative
Quoted Lead Time: The agreed upon time between the placement of an order and the order being ready for distribution. The quoted lead time results in a due date.
Produce up-to Level: On-hand Stock, after production but before demand.
Routing Group: A routing group is a set of articles that share the same mold

16 Table of Appendices

Appendix A – Production Locations & Sales Regions 1
Appendix B – Seasonal Demand 2
Appendix C – Level Production 3
Appendix D – Stock Turnover 4
Appendix E – Production Data 5
Appendix F – Setup Frequency 6
Appendix G – Triangular Distribution 7
Appendix H – VBA Code 8
Appendix I – Input Data 15
Appendix J – Output Data 22

Appendix A – Production Locations & Sales Regions

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Figure A-1 **“Production Sites and Sales Regions”**

Appendix B – Seasonal Demand

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Appendix C – Level Production

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Appendix D – Stock Turnover

<<confidential>>

Appendix E – Production Data

<<confidential>>

Appendix F – Setup Frequency

<<confidential>>

Appendix G – Triangular Distribution

In probability theory and statistics, the triangular distribution[1] is a continuous probability distribution with lower limit a, mode c and upper limit b. In this situation the mode is equal to the lower limit; $c = a$. The random variable x is located between a and b. We will first give the mathematical representation of the probability density function, cumulative distribution function and the expected value of x. Second, we will present two figures depicting the functions. See Figure G-1 for the probability density function. See Figure G-2 for the cumulative distribution function.

$\phi(x)$: Probability density function for random variable x

$\Phi(x)$: Cumulative distribution function for random variable x

$$\phi(x) = \begin{cases} 0 & ,x < a \\ \dfrac{2(b-x)}{(b-a)^2} & ,a \leq x \leq b \\ 0 & ,x > b \end{cases} \tag{G.1}$$

$$\Phi(x) = \begin{cases} 0 & ,x < a \\ 1 - \dfrac{(b-x)^2}{(b-a)^2} & ,a \leq x \leq b \\ 1 & ,x > b \end{cases} \tag{G.2}$$

$$E(x) = \frac{2a+b}{3} \tag{G.3}$$

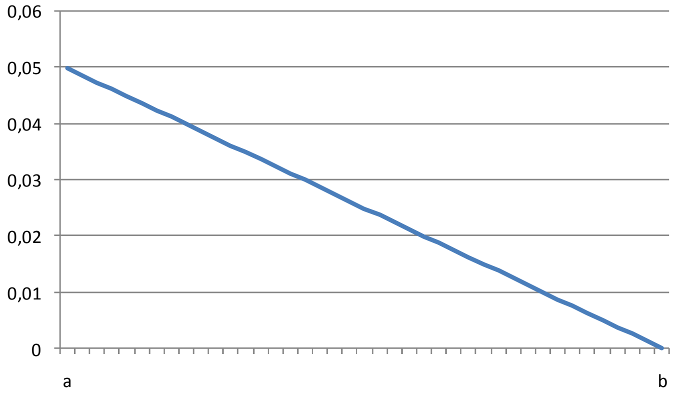

Figure G-1 **“Probability Density Function”**

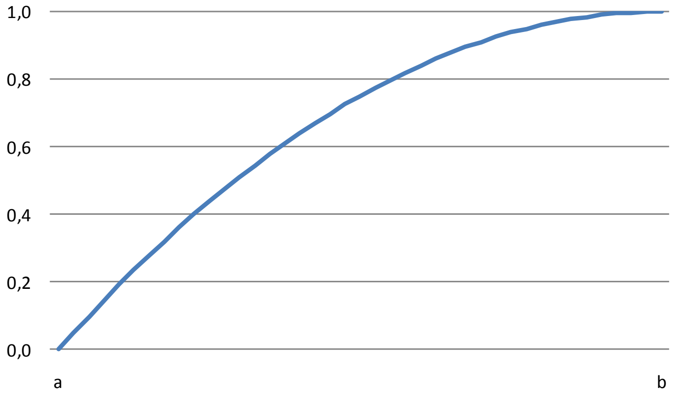

Figure G-2 **“Cumulative Distribution Function”**

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[1] http://en.wikipedia.org/wiki/Triangular_distribution

Appendix H – VBA Code

Each Sub procedure is enclosed by the 'Sub' and 'End Sub' statements. Comments are added in green and preceded by an apostrophe (').

MA Heuristic

```
Sub MA_1()

Sheets("Heuristic").Select
'j=1
Cells(4, 3).Formula = 1

'clear production quantities
Application.Goto reference:="heuristic_pq"
Selection.ClearContents

'Attempt to produce the quantities due in the current period

Range("heuristic_pq_al_1").Select
Application.CutCopyMode = False
Selection.Copy

Range("heuristic_pq").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

'Count the number of setups
Run "heuristic_setup"

'Get the result of equation 7.7
Sheets("Heuristic").Select
r_plus = Cells(8, 9).Value

'Check if the quantitues due in the current period are within reach

If r_plus > 0 Then Run "MA_4" Else Run "AL_1_1"

End Sub
```

```
Sub MA_4()

Sheets("Heuristic").Select
Application.Goto reference:="heuristic_pq"
Selection.ClearContents

'Attempt to produce up to the optimal levels in the current period

Range("heuristic_pq_al_2").Select
Application.CutCopyMode = False
Selection.Copy

Range("heuristic_pq").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

'Count the number of setups
Run "heuristic_setup"

'Get the result of equation 7.7
Sheets("Heuristic").Select
r_plus = Cells(8, 9).Value

'Check if the optimal levels in the current period are within reach

If r_plus > 0 Then Run "AN_1" Else Run "AL_2_1"

End Sub
```

Procedure Allocate

Procedure Allocate in case the quantities due are not within reach

```
Sub AL_1_1()
Sheets("Heuristic").Select
```

```
'clear production quantities
Application.Goto reference:="heuristic_pq"
Selection.ClearContents

'Count the number of setups
Run "heuristic_setup"

Run "AL_1_4"
End Sub
```

```
Sub AL_1_4()
Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_1"))

If list_value = 0 Then

'Procedure Allocate Select

Sheets("SetupSelect").Select
pc_value =
Application.WorksheetFunction.Count(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_pc_al_1"))

If pc_value = 0 Then

Else

max_value =
Application.WorksheetFunction.Max(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_pc_al_1"))
art_row = Application.WorksheetFunction.Match(max_value, ThisWorkbook.Sheets("SetupSelect").Range("U:U"), 0)
art_ref = Cells(art_row, 1).Value

'Add the article to the list by producing 1 unit
Sheets("Heuristic").Select
pq_value = Cells(art_row + 10, 6).Value
pq_add = 1

Cells(art_row + 10, 6).Formula = pq_value + pq_add

'Count a setup
Run "heuristic_setup_art", art_ref

End If

Else

End If

Run "Al_1_5"

End Sub
```

```
Sub AL_1_5()
Sheets("Heuristic").Select
Calculate

'Get the stepsize
stepsize = Cells(8, 26).Value

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_1"))

'Get the result of equation 7.7
r_plus = Cells(8, 9).Value

Do While list_value > 0 And r_plus > 0

max_value = Application.WorksheetFunction.Max(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_1"))
art_row = Application.WorksheetFunction.Match(max_value, ThisWorkbook.Sheets("Heuristic").Range("Z:Z"), 0)

art_ref = Cells(art_row, 1).Value

'AL_6
pq_value = Cells(art_row, 6).Value
al_1_value = Cells(art_row, 3).Value
```

```
pq_add = Application.WorksheetFunction.Min(stepsize / art(art_ref, "rou_rate"), al_1_value)

Cells(art_row, 6).Formula = pq_value + pq_add

Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_1"))

'Get the result of equation 7.7
r_plus = Cells(8, 9).Value

Loop

If r_plus > 0 Then Run "AL_1_4"

End Sub
```

Procedure Allocate in case the optimal produce up-to levels are not within reach

```
Sub AL_2_1()
Sheets("Heuristic").Select
Application.Goto reference:="heuristic_pq"
Selection.ClearContents

'Produce the quantities due in the current period
Range("heuristic_pq_al_1").Select
Application.CutCopyMode = False
Selection.Copy

Range("heuristic_pq").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

'Count the number of setups
Run "heuristic_setup"

Run "AL_2_4"
End Sub
```

```
Sub AL_2_4()
Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_2"))

If list_value = 0 Then

'Procedure Allocate Select

Sheets("SetupSelect").Select
pc_value =
Application.WorksheetFunction.Count(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_pc_al_2"))

If pc_value = 0 Then

Else

max_value =
Application.WorksheetFunction.Max(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_pc_al_2"))
art_row = Application.WorksheetFunction.Match(max_value, ThisWorkbook.Sheets("SetupSelect").Range("V:V"), 0)
art_ref = Cells(art_row, 1).Value

'Add the article to the list by producing 1 unit
Sheets("Heuristic").Select
pq_value = Cells(art_row + 10, 6).Value
pq_add = 1

Cells(art_row + 10, 6).Formula = pq_value + pq_add

'Count a setup
Run "heuristic_setup_art", art_ref

End If
```

```
Else

End If


Run "Al_2_5"

End Sub
```

```
Sub AL_2_5()
Sheets("Heuristic").Select
Calculate

'Get the stepsize
stepsize = Cells(8, 26).Value

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_2"))

'Get the result of equation 7.7
r_plus = Cells(8, 9).Value

Do While list_value > 0 And r_plus > 0

max_value = Application.WorksheetFunction.Max(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_2"))
art_row = Application.WorksheetFunction.Match(max_value, ThisWorkbook.Sheets("Heuristic").Range("AB:AB"), 0)

art_ref = Cells(art_row, 1).Value

'AL_6
pq_value = Cells(art_row, 6).Value
al_2_value = Cells(art_row, 4).Value

pq_add = Application.WorksheetFunction.Min(stepsize / art(art_ref, "rou_rate"), al_2_value)

Cells(art_row, 6).Formula = pq_value + pq_add

Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_al_2"))

'Get the result of equation 7.7
r_plus = Cells(8, 9).Value

Loop

If r_plus > 0 Then Run "AL_2_4"

End Sub
```

Procedure Anticipate

```
Sub AN_1()

'j=2
Cells(4, 3).Formula = 2

Run "AN_7"

End Sub
```

```
Sub AN_7()
Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_an"))

If list_value = 0 Then

'Procedure Anticipate Select

Sheets("SetupSelect").Select
hc_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_hc"))
```

```
If hc_value = 0 Then

'widen the horizon
Run "AN_11"

Else

min_value = Application.WorksheetFunction.Min(ThisWorkbook.Sheets("SetupSelect").Range("setupselect_hc"))
art_row = Application.WorksheetFunction.Match(min_value, ThisWorkbook.Sheets("SetupSelect").Range("X:X"), 0)
art_ref = Cells(art_row, 1).Value

'Add the article to the list by producing 1 unit
Sheets("Heuristic").Select
pq_value = Cells(art_row + 10, 6).Value
pq_add = 1

Cells(art_row + 10, 6).Formula = pq_value + pq_add

'Count a setup
Run "heuristic_setup_art", art_ref

End If

Else

End If

Run "AN_9"

End Sub
```

```
Sub AN_9()
Sheets("Heuristic").Select
Calculate

'get the stepsize
stepsize = Cells(8, 26).Value

'get the future period
j_value = Cells(4, 3).Value

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_an"))

'get the result of equation 7.7
r_plus = Cells(8, 9).Value

'get the result of equation 7.11
r_short = Cells(8, 3).Value

Do While list_value > 0 And r_plus > 0 And r_short > 0

min_value = Application.WorksheetFunction.Min(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_an"))
art_row = Application.WorksheetFunction.Match(min_value, ThisWorkbook.Sheets("Heuristic").Range("AH:AH"), 0)

art_ref = Cells(art_row, 1).Value

'AN_10
pq_value = Cells(art_row, 6).Value
an_value = Cells(art_row, 9 + j_value).Value

pq_add = Application.WorksheetFunction.Min(stepsize / art(art_ref, "rou_rate"), an_value)

Cells(art_row, 6).Formula = pq_value + pq_add

Sheets("Heuristic").Select
Calculate

'Check if there are articles in the eligible list
list_value = Application.WorksheetFunction.Count(ThisWorkbook.Sheets("Heuristic").Range("heuristic_l_an"))

'get the result of equation 7.7
r_plus = Cells(8, 9).Value

'get the result of equation 7.11
r_short = Cells(8, 3).Value

Loop
If r_plus < 0 Then MsgBox "End"
If r_plus > 0 And r_short > 0 Then Run "AN_7"

'widen the horizon
If r_plus > 0 And r_short < 0 Then Run "AN_11"
End Sub
```

```
Sub AN_11()
Sheets("Heuristic").Select
ActiveWorkbook.Save

'get the future period
j_value = Cells(4, 3).Value

If j_value < 12 Then

'widen the horizon
Cells(4, 3).Formula = j_value + 1

Run "AN_7"

Else

End If
End Sub
```

Setup Count

Setups in Equation 7.7

```
Sub heuristic_setup_art(art_ref As Variant)
Application.Calculation = xlManual

'get the routing group of the article
rou_ref = art(art_ref, "art_rou")

'add a small setup to the routing group
Sheets("HSetups").Select
rou_lookup = Application.WorksheetFunction.Match(rou_ref, Range("A:A"), 0)

setup_value = Cells(rou_lookup, 3).Value
Cells(rou_lookup, 3).Formula = setup_value + 1

Sheets("Heuristic").Select

Application.Calculation = xlAutomatic
End Sub
```

Setups in Equation 7.10

```
Sub heuristic_setup()
Application.Calculation = xlManual

'clear setups counted
Sheets("HSetups").Select

    Application.Goto reference:="hsetups_setup_1"
    Selection.ClearContents

'count the number of setups used
Sheets("Heuristic").Select
For Each Cell In Range("heuristic_pq")
pq_value = Cell.Value

Select Case pq_value
Case Is > 0

art_row = Cell.Row

'get the routing group of the article
art_ref = Cells(art_row, 1).Value
rou_ref = art(art_ref, "art_rou")

'add a small setup to the routing group
Sheets("HSetups").Select
rou_lookup = Application.WorksheetFunction.Match(rou_ref, Range("A:A"), 0)
```

```
setup_value = Cells(rou_lookup, 3).Value
Cells(rou_lookup, 3).Formula = setup_value + 1

Sheets("Heuristic").Select
Case Else

End Select

Next

Application.Calculation = xlAutomatic
End Sub
```

Appendix I– Input Data

To avoid confusion on the origins of the data we used, we give a detailed description in this appendix. This is appendix is written for SVI and should help users to collect the necessary input data for the tool. Most sources will be familiar for the intended users; the operational and tactical planner. We will however explicitly refer to the source files, described the sources and explain the modifications.

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Appendix J – Output Data

The outputs for scenarios 1 to 7 and the current situation (before the implementation of the redesign) can be found in this appendix. Each output consists of graph that depicts the number of hours in effective production time stocked. Second, we will present a graph with the holding costs and penalty costs. We did a scenario analysis from March 2007 until November 2008. Yearly comparison will be made based on July 2007 until June 2008. At the end we will present a table with the capacity usage, the number of hours in lost sales and the number of months that is looked ahead in case Procedure Anticipate is evoked. (Note that a lead of 2 means that we looked 1 month ahead).

The results of the scenarios are discussed in the insights section of Chapter 10. The interested reader can use the figures and tables in this chapter to verify the insight arrived at in Chapter 10. The reader can also verify and falsify (part of his) own ideas and presumptions.

Scenario 1

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Scenario 2

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Scenario 3

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Scenario 4

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Scenario 5

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Scenario 6

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Scenario 7

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Current Situation

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