Batch sizing in the Architectural Coatings supply chain

An analysis of the economical feasibility of reducing batch sizes to save inventory

PUBLIC VERSION

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MANAGEMENT SUMMARY

PPG Industries Inc. is a global supplier of coatings (performance, industrial, and architectural coatings) and specialty products (optical materials and specialty materials, glass, and commodity chemicals). The scope of this thesis lies within the Architectural Coatings (AC) Europe, Middle East, and Africa (EMEA) Business Section of the company. More specifically, the central issue of the project lies within the Western European (WE) Supply Organization.

AC EMEA WE produces and distributes a wide range of architectural coatings: approximately 40 brands, each comprising of a full range of colors and package volumes. Supplying numerous different unique Stock Keeping Units (SKUs) at a high service level requires a responsive, lean organization; yet to a certain extent, this demand could also be compensated by holding high finished goods inventory. Producing in a responsive manner requires smaller batches, hence high setup costs as well as capacity loss, whereas holding excess stock yields high inventory cost and lays a burden on working capital.

The central matter of interest in this thesis is:

"Is it economically feasible to reduce inventory in the AC EMEA supply chain by producing in smaller batch sizes?"

This research shows that producing smaller batches in order to save inventory is an economically feasible line of action. The batch size optimization process in its full dynamics and complexity is rather cumbersome, yet a simpler model such as the one built for this research's purposes already yields some useful decision support for determining the appropriate lot size for a specific product at a certain time.

Supported by the model, we propose some specific alterations in parts of the 1100-SKU product range of the Uithoorn factory. Currently, a policy of large batches characterizes the production side of the Western European supply chain. Some capacity constraints may arise when altering the batch sizes and increasing setup frequency. PPG AC EMEA employees should bear this in mind, while simultaneously being watchful for opportunities to decrease setup times or (re-)engineer processes in such a way that it enhances the new, responsive production approach. Increasing setups may contradict many people's intuition. From that perspective, it is not surprising that there is so much literature and discussion on this topic.

Literature on batch sizing shows several ways to simplify the rather complex capacity constrained, multi-level, multi-product factory context. Assumptions need to be made on several aspects of the problem and its environment to find a feasible solution. The assumption on the nature of demand is rather momentous; a constant-demand assumption leads to the more intuitive EOQ-models, while deterministic and stochastic dynamic demand premises bring forth economic lot scheduling problems (ELSPs) and stochastic economic lot scheduling problems (SELSPs) respectively.

The model constructed for this research combines the knowledge on batch size optimization with real data from the AC EMEA factories. An intuitive EOQ-like approach has been chosen, thereby keeping model complexity relatively low while slightly raising the intricacy of interpreting the model's results. The model can be used to make the trade-off between increased setup cost and decreased inventory holding cost for any product produced in the VFU factory, yet it is also suitable for other factories if some parameters are adjusted and new data is included.

Preferably, batch size trade-offs within the AC EMEA supply chain should be supported by up-to-date optimization calculations, which take into account relevant factors such as current inventories and demand patterns. When analyzing the desired situation as compared to the current supply process, the key discrepancy is the lack of precisely that quantitative decision support – there is no up to date data on the optimality of batch sizes. Therefore, SKUs are produced in sub-optimal quantities (that are generally larger than the optimum).

Quite some discussion concerning the effects of batch size alterations is going on within AC EMEA. We have seen that there is no apparent universal rule that states whether small batches or large batches are optimal. On the contrary, each SKU has its own unique properties, leading to a different optimum. Proper decision support on optimal batch sizing will resolve this discord on making small or large batches. Furthermore, this will shift the focus of the discussion towards the way in which the optimal batch sizes should be calculated, ultimately yielding even better batch sizing decision models.

ACKNOWLEDGEMENTS

This Bachelor Thesis is the final step in acquiring my Bachelor of Science degree in Industrial Engineering and Management at the Faculty of Management and Governance at the University of Twente. I conducted my research on a batch sizing and inventory problem at PPG Industries AC EMEA. I have primarily been working from the Northern European headquarters in Uithoorn, The Netherlands. I visited the Verffabriek Uithoorn regularly, and have also seen the Amsterdam Factory and Warehouse on several occasions. In its entirety, it has been a very rewarding experience for me. It was nice to work on this project, to meet many PPG employees, and I most certainly have derived some lessons from working on this thesis.

I sincerely thank everybody who has been engaged in explaining all kinds of aspects of AC EMEA Supply to me, those who have shown me around in the factories and the warehouse, those who have given me access to information and data of various sorts, those who have provided me with feedback and good debates, and last but not least everyone who has made working on this thesis and my internship at PPG an enjoyable experience.

Special thanks go out to PPG AC EMEA's Remko Spruijt, for supervising me during the project in a very enthusiastic, stimulating manner. I also thank Steve Jackson, for giving me the opportunity to work on this project and for staying involved throughout the process. Also, particular thanks go out to Marco Schutten, for supervising my thesis from the perspective of the University of Twente.

Pim Oude Alink

Enschede, May 2012

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DEFINITIONS

ORGANIZATION

AC	Architectural Coatings
EMEA	Europe, Middle East and Africa
WE	Western Europe
EE	Eastern Europe
AMEFO	Africa, Middle East, & French Overseas
RNE	Region Northern Europe
SBU	Strategic Business Unit
Supply	The AC EMEA Supply Organization
Demand	The AC EMEA Demand Organization
VFU	Verffabriek Uithoorn (factory)
VFA	Verffabriek Amsterdam (factory)
VFDB	Verffabriek Den Bosch (factory)
DCG	Distributiecentrum Giesen (warehouse)
DCA	Distributiecentrum Amsterdam (warehouse)

LOT SIZING PROBLEMS AND MODELS

EOQ	Economic Order Quantity
ELSP	Economic Lot Scheduling Problem
SELSP	Stochastic ELSP
MFELSP	Multi-Family ELSP
WW problem	Wagner-Whitin problem
TVLS	Time-Varying Lot size
SDS	Sequence-Dependent Setups

PROCESSES AND COSTING

DOI	Days of inventory
SKU	Stock Keeping Unit
ABC	Activity Based Costing
ERP system	Enterprise Resource Planning system
RM	Raw Materials Cost
Pack	Packaging Cost
LHC	Labor Hour Cost
MHC	Machine Hour Cost
FBC	Fixed Batch Cost
FKC	Fixed Kilo Cost
FLC	Fixed Liter Cost
Other	Other Cost

PRODUCTION PROCESS

Premix	Semi-manufactured product from a single dissolver
NUP	Semi-manufactured product
HALB	Semi-manufactured product
FERT	Finished product

1 - INTRODUCTION

This chapter introduces, explains, and defines the central issue of this thesis and presents a problem approach. Section 1.1 briefly introduces the central theme and outlines the structure of this thesis. Section 1.2 presents some necessary backgrounds on the company, some aspects of the organization, the full problem description, and its strategic relevance, to provide insight into the context and implications of the core problem. This lays a foundation for the research design, as discussed in Section 1.3.

1.1 CENTRAL THEME OF THE PROJECT

This project is set up by the Supply Organization of the Architectural Coatings Europe, Middle East, and Africa (AC EMEA) Business Section, which is a business segment of the PPG Industries multinational. The direct cause for the project is an Inventory Reduction Program that is currently carried out, which aims at aligning the supply capabilities of the Business Segment with the demand for an increasing amount of different products. More specifically, the scope of this research is on the implications of producing smaller batches of paint within the Western European production facilities. In short, the main research question is:

"Is it economically feasible to reduce inventory in the AC EMEA supply chain by producing in smaller batch sizes?"

Section 1.2 explains the context of the research as well as the project's aim more elaborately.

1.2 PROBLEM DEFINITION

1.2.1 THE COMPANY AND ITS BUSINESS SEGMENTS

PPG Industries Inc. is a multinational company, supplying paints, coatings, optical products, specialty materials, chemicals, glass, and fiber glass to the global market. With its headquarters based in Pittsburgh, Pennsylvania, USA, the company runs operations in over 60 countries around the globe. PPG Architectural Coatings (AC) Europe, Middle East, and Africa (EMEA), has been acquired by PPG Industries in 2008. Formerly, AC EMEA was a private limited company known as the SigmaKalon Group. For a more elaborate description of PPG's and AC EMEA's backgrounds, see Appendix A.

Table 1 shows some key figures of the company, including sales and earnings of AC EMEA and the five other Business Segments that PPG Industries consists of. Up to today, AC EMEA has not been integrated with the other AC parts of PPG. The main reason for doing so is to directly show return on investment of this huge acquisition to the shareholder. Eventually, AC EMEA may be merged with the AC Strategic Business Unit (SBU) for the Americas and Asia/Pacific that is currently positioned under the Performance Coatings Business Segment.

2010 Review	
Net Sales	13.4 B$
Net Income	769 M$
Earnings per Share	4.63 $
Average Shares Outstanding	165.9 M
Average Employees	38.300
Capital Spending	341 M$
Research and Development	408 M$

	Sales (B$)	Earnings (B$)
Performance Coatings	4.281	661
Industrial Coatings	3.708	378
Architectural Coatings EMEA	1.874	113
Optical and Speciality Materials	1.141	307
Commodity Chemicals	1.434	189
Glass	985	74
Total	13.423	1.722

Table 1 - Key figures for PPG Industries over 2010.

1.2.2 Organizational Context

AC EMEA is the second largest supplier of architectural coatings and sundry products in Europe, selling decorative coatings via a network of more than 500 owned service centers and over 3,000 independent wholesalers. In 2010, sales were 1.8 billion USD, which equals 14% of total PPG Industries' sales. The AC EMEA Business Segment consists of 26 production sites, 42 warehouses, and is divided into three regions: Western Europe (WE), Eastern Europe (EE), and Africa, Middle East, and French Overseas (AMEFO). Table 2 gives an overview of the main production and distribution properties of the three regions.

<<Table confidential>>

Table 2 - Overview of AC EMEA's production and distribution.

PPG AC WE comprises of four business units: Region Northern Europe (RNE), Region Southern Europe, Region UK/Ireland, and Retail Europe. In 2010, a WE Supply Organization was formed to manage the Manufacturing, Logistics, and Planning operations on a more pan-European basis in order to address particular problems and to ensure that sharing of best practice takes place in a more coordinated manner within the entire region. Later in 2010, the demand functions in these regions (Sales, Strategic Marketing, et cetera) were aligned under a Demand Organization, with Supply and Demand from that moment on being managed by a Vice President for AC WE.

1.2.3 Problem Context

The central issues of this project are embedded in the AC WE supply chain and form part of a wider AC EMEA Inventory Reduction Project, which is managed by the Supply department. Overall, AC WE currently has approximately 110 Days of Inventory (DOI). The market has developed to a mature state, with lower margins and fiercer competition. During the past times of market growth, the production and distribution facilities have been designed for efficiency on high output volumes, resulting in a current state of overcapacity.

Recent benchmarking within the market by Orr and Boss has shown that AC EMEA's average batch size is smaller than that of competitors. This is not surprising considering the complexity of the product portfolio; AC EMEA produces over 40 brands of paint and some own-brand paints for retail organizations on top of that. There are many unique product types on stock; each having different brands, formulas, package forms, and package volumes. The term Stock Keeping Unit (SKU) refers to each of these unique products.

Nevertheless, there is constant pressure from the Demand department to further increase the range of products and thereby either increase inventory or produce even smaller batches of each SKU, causing an increase in complexity. The latter does not reconcile with the current alignment of the production facilities on high volumes, hence leading to longer lead times along with excessive production volumes for low-demand SKUs.

AC EMEA offers high service levels to its customers, amounting to on-time delivery levels ranging from 95 to 98%. Customers are not restricted to fixed ordering volumes or any other constraints, resulting in an instable and unpredictable demand pattern. Along with the long lead times, these issues drive up the safety stocks in the warehouses, resulting in the high DOI. In order to structure the problem context, Figure 1 gives a graphical representation of the problem context, showing some generalized cause-and-effect relationships.

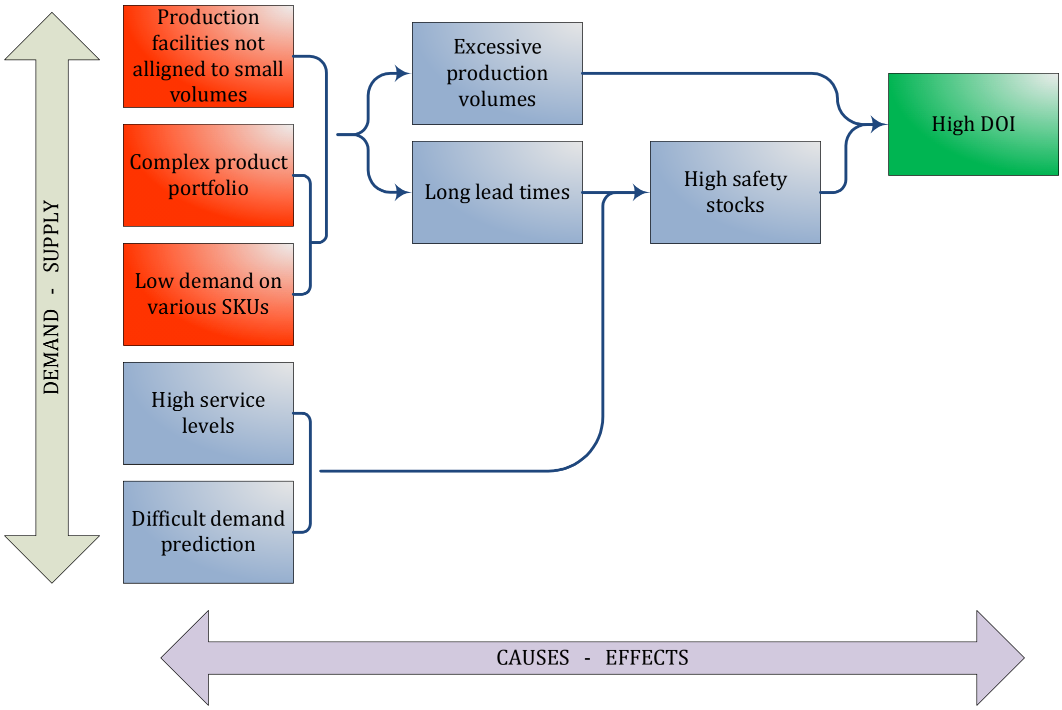


Figure 1 - Problem bundle representing the problem context. The causes that are most relevant for the project are colored red.

1.2.4 The Challenge

Sponsored by Supply, this project aims on bridging the gap between the alignments of the production facilities on the one hand and the complexity of the product portfolio together with a low demand on various SKUs on the other hand. Consequently, there will be less excessive production volumes and lead times should decrease, resulting in lower safety stocks and lower DOI.

The key to unlocking this potential plausibly lies in the batch sizes used for production, because if it would be economically feasible to produce small batches, then the complexity of the product portfolio will have less inflating impact on the DOI. However, the problem is that it is generally assumed to be more expensive to produce smaller batches, so this will probably also be the case for the specific situation within AC EMEA. Moreover, there are some constraints within production facilities on minimum batch sizes. The challenge is to determine what possibilities AC EMEA has to produce small batches.

The current data in AC EMEA's costing models show the difference in production costs between various batch sizes. This probably does not reflect the 'true' picture; the costing model may not account for hidden cost. On the other hand, the impact of batch sizes on inventories/working capital is significant. Therefore, the relationship between batch size, production cost, and inventory cost needs to be defined in order to subsequently determine whether the perceived increase in production cost outweighs the perceived decrease in inventory cost.

1.2.5 Strategic Relevance

AC EMEA Supply's mission is to realize sustainable supply achieving service levels and quality agreed with Demand at lowest possible cost. This project encompasses aspects of *realizing sustainable supply* at *lowest possible cost* and therefore fits right into the mission of AC EMEA Supply, thereby emphasizing its relevance.

1.3 RESEARCH DESIGN

1.3.1 Problem and Research Questions

As introduced in Section 1.2, the core problem of this project can be summarized as: "The market-driven demand to enlarge the range of SKUs, thus increasing the complexity of the product portfolio, is not answered by the current (perception of) supply capabilities of AC EMEA."

As stated in Section 1.2, these (perceived) supply capabilities currently result in high inventories. The scope of this thesis mainly is to find out how to reduce inventory under the current broad range of SKUs, by researching the trade-off between batch sizes in production and inventory. The respective knowledge problem is defined as:

"Is it economically feasible to reduce inventory in the AC EMEA supply chain by producing in smaller batch sizes?"

This corresponds to the main research question in Section 1.1. Furthermore, there are five sub-questions that build to answering the main research question, namely:

1) *What is the current situation regarding supply? (Chapter 2)*
2) *What does literature say about batch sizing and the economic feasibility of batch size reduction? (Chapter 3)*
3) *What is the desired situation regarding supply? (Chapter 4)*
4) *Can the discrepancy between current and desired be bridged by making smaller batch sizes?*
    i. *What is the influence of batch sizes on operating cost? (Chapter 4)*
    ii. *What is the influence of batch sizes on inventory cost? (Chapter 4)*
    iii. *Under what conditions is producing in smaller batch sizes economically feasible? (Chapter 5)*

As can be seen, these questions roughly correspond to the structure of this thesis. In Chapter 6, the answers to each of these questions are summarized briefly, thereby leading to a full conclusion on the main research question.

1.3.2 Variables and Indicators

Three important concepts have been introduced in the previous sections of this chapter: batch size, operating cost, and inventory cost. All relate to the main research question. As can be seen from the outline of the thesis structure as well as the research sub-questions, the main variables that are studied in this thesis are:

- The correlation between batch size and operating cost, and
- The correlation between batch size and inventory cost.

Table 3 displays the indicators of each of the variables. Chapter 2 explains the specific choices for these indicators in more detail.

Batch size	Operating cost (EUR/kg)	Inventory cost (EUR/kg)
• Quantity per production batch in Kg (semi-manufactured product); • Volume per filling batch in Liter (finished product).	•Raw Materials Cost (RM); •Fixed Batch Cost (FBC); •Packaging Cost (Pack); •Fixed Kilo Cost (FKC); •Labor Hours Cost (LHC); •Fixed Liter Cost (FLC); •Machine Hours Cost (MHC).	• Holding Cost (value of stock during year * % cost of holding that stock for a year).

Table 3 - Overview of the indicators of the variables that define the knowledge problem.

1.3.3 Project Scope

As addressed in Section 1.2.3, this research focuses mainly on the Western European supply chain. More specifically, the main focus is on the Verffabriek Uithoorn (VFU) and Verffabriek Amsterdam (VFA) factories, as well as the Distributiecentrum Amsterdam (DCA), in which the inventory from both these factories is being held.

Because the VFU factory relatively has low complexity in design and product portfolio, this is a suitable target for research. Moreover, this causes the production data to show a rather limited amount of noise, which is good for this research's purpose; therefore this factory's data sets are the basis for most of the data research. The VFA factory on the other hand is comparatively a lot more complicated so in order for the research results to be generally applicable to the rest of AC EMEA, references and comparisons to the VFA factory are made regularly.

1.3.4 Thesis Structure

Before going in to the implications of altering batch sizes, Chapter 2 defines aspects of the current situation within the company that are relevant for this project. Consequently, Chapter 3 holds a theoretical framework to support further analysis. In Chapter 4, the analysis on this subject is presented. An experimental model is introduced in Chapter 5, along with its implications for the company. Chapter 6 comprises of the conclusions and recommendations; all research questions are revisited and answered accordingly. Also, it addresses some relevant implementation issues for carrying forward this project.

2 – CURRENT SITUATION

This chapter addresses four main aspects of the current situation that are most relevant for this project. First, the Dutch AC supply chain is described in Section 2.1, followed by a description of the paint production process in Section 2.2, along with information on costing. Section 2.3 thereafter reveals the most important details on warehousing. Because the scope of this research is on batch sizes, Section 2.4 addresses the current method of batch size planning and the organizational entities involved.

2.1 SUPPLY CHAIN

The Dutch supply chain for Architectural Coatings comprises of two warehouses, namely Distributiecentrum Amsterdam and Giessen (DCA and DCG), along with three factories, called Verffabriek Uithoorn, Amsterdam, and Den Bosch (VFU, VFA, and VFDB). The warehouse in Giessen is not owned by PPG. Products of one of the PPG AC brands (mainly plasters; the brand is called Brander) are handled there. Figure 2 summarizes the main links in the chain. In the figure, the main product group that each of the locations is focused on is specified.

The Amsterdam factory is the largest in labor (FTEs), physical dimensions, and number of SKUs produced. The Uithoorn factory however, is the largest in production output, with a production of <<>>kT per year, followed by Amsterdam with <<>>kT, and Den Bosch with <<>>kT. Due to the different nature of the goods produced in each of the factories, the production processes and related costs are distinctively different.

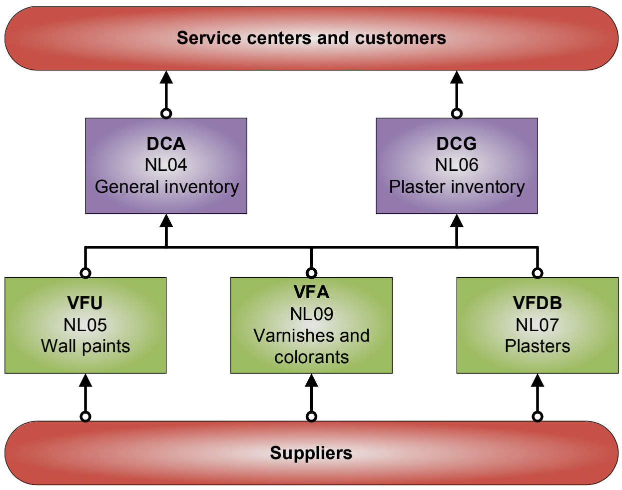


Figure 2 - Overview of the Dutch AC supply chain.

2.2 PRODUCTION

2.2.1 The Paint Production Process

A paint production process typically consists of two main stages: production and filling. In production, the ingredients, specified by the Bill of Materials (BOM), are blended together in such a way that a smooth mixture is obtained. This process is called dispersion. Ingredients generally include a binding agent (40~50%), filler and pigment (20~30%), solvent (20~25%), and some additives. After dispersion, the resulting mixture, also referred to as the premix, is generally pumped to a mixing tank, finishing tank, or bulk tank.

Often, multiple premixes are combined in one tank. In all three types of tanks, the binding agent is added to the mixture and the paint is homogenized. Additionally, in a finishing tank some adjustments are made to the paint properties. Moreover, bulk tanks are used to store considerable quantities of paint, in order to cope with demand fluctuations for top-selling paints.

Eventually, the paint is filled into different packaging units on the filling line, and prepared for shipment. A quality inspection is carried out both after the dispersion and before the filling process; the second being more elaborate and stringent than the first.

Usually, the tinting of the paint either takes place during production, at the warehouse, or at the retailer (using a colorant and a tinting device). In the latter case, the paint shipped to the retailer is called 'base paint', whereas it is called 'ready-mix paint' in case tinting takes place during production. In an average factory, the production and filling lines for white and color paints are strictly separated, in order to prevent quality loss through contamination and unnecessary cleaning procedures for all tanks and pipelines after each batch.

Within the production process there are quite some activities, many of which being partly or fully automated. Furthermore, some indirect activities are carried out, such as maintenance and operations management. Figure 3 introduces an overview of common activities within factories.

Factory Activities					
Direct				*Indirect*	
Raw materials	Production	Packaging	Filling	Process support/mgmt	General support
Ordering	Pre batching	Ordering	Pre batching	Operations management	Plant administration
Recieving	Dosing	Recieving	Filling	Supply chain planning	General factory supplies
Storing	Mixing	Storing	Quality control	Human resources	Plant services
Issuing	Tinting	Issuing	Palletizing	Maintenance	Safety, Health, Environment, Quality
	Quality control	Labeling	Readying for transport	Local IT	
	Waiting time		Waiting time	Waste treatment	
				Processing & technology	
				Technical packaging	

Figure 3 - Overview of activities in the production process.

2.2.2 The Complexity in Paint Production

When compared to other chemical production processes, the paint production process is considered to be quite elementary. Nonetheless, a lot of complexity is derived from the huge amount of different SKUs that are being produced in an average paint production facility. For instance, the VFU plant in Uithoorn alone produces over 1100 different SKUs of water-based wall paint. These SKUs are covered by approximately 340 types of paint: each paint type generally has multiple package volumes and forms. Combined with the limitedness of production capacities, this creates a complex operating space for the Supply organization of PPG AC EMEA. Furthermore, the drastic seasonality and fluctuations in demand contribute to this complexity, as well as the tendency to keep inventory levels suitably low.

In any paint factory, there are multiple routings that can be used to produce a specific kind of paint. A routing determines the path that is used from raw materials to finished goods, and therefore incorporates what machines and tanks will be used. The routing also determines the quantities that are produced in that particular batch, because each dissolver and tank has its own upper and lower capacity bounds. Figure 4 provides an overview of the three most important steps in production that are determined by a routing.

Figure 4 also shows the relationship between pre-mixes, semi-manufactured product, and finished product. Semi-manufactured product is often referred to as NUP (abbreviation for 'niet uitgevuld product') or HALB (short for 'Halbfabrikat' in SAP), whereas the finished product is often called SKU or FERT (short for 'Fertigfabrikat' in SAP). One or multiple pre-mixes can be combined to one HALB, and one HALB generally is filled into multiple packages on one or more filling lines. Concluding, one or more multiple SKUs can be filled from one production batch, and routings can be used to obtain the desired amount of paint of certain SKUs.

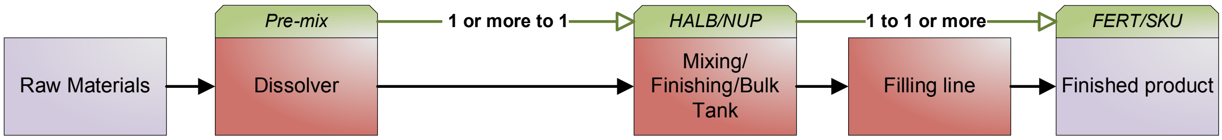


Figure 4 – Simplified view of the stages in paint production.

There is a limited set of possible combinations of production assets, and therefore the number of routings also is limited. Some routings can be used to produce batches of large quantities (up to 30,000 kg), while others are more aligned to small volumes (from 1,100kg). White and base paints generally are sold in large packaging units like 10l, 12.5l, and 15l; color paints are usually sold in smaller packages of 1l, 2.5l, and 5l for instance. As addressed in Section 2.2.1, it is necessary to separate the lines for color and white paints. Therefore, some routings are dedicated to color paints in small volumes, while other routings are committed to white paints in large volumes. Nevertheless, some routings can be used for both, for instance it does occur that a white paint SKU with a small package volume is filled on a color line.

2.2.3 The VFU Factory

The VFU production facility roughly encompasses loading docks, storage (mainly raw materials, Packaging, and rejected semi- manufactured paint), some different kinds of production lines, filling lines, and tanks, and some offices for planning, support, and management. Because the process consists of quite some steps, Figure 5 gives a generalized scheme of any paint production process, based on the VFU factory.

On the left side of the figure, the raw materials and packaging inventories are shown. The raw materials are released into a dissolver, and then homogenized, tested for quality, and pumped into either a mixing, finishing or bulk tank (depending on the paint type). Again, quality is tested, but now more accurately. When quality meets the standards, the paint is then pumped to one of the filling lines. At the filling lines, the packaging is filled with paint, sealed, tagged, and palletized. Finally, the full pallet is wrapped, conveyed to the loading bays, and mounted to a truck. Appendix B shows a more detailed scheme of the factory process.

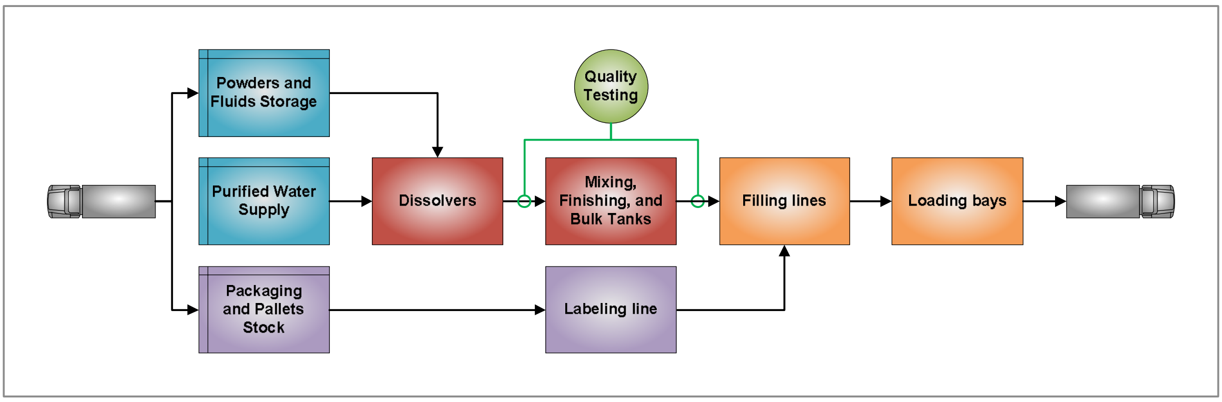


Figure 5 – Simplified VFU production layout

In 2010, the VFU had an output of approximately <<>>kT of paint, equaling about 14% of the total Western European production. Some general information on 2010 production is given in Table 4, showing the significant difference between white and color routing parameter values. What strikes most is the much lower NUP/SKU ratio for the white routing paints. Apparently, the average white paint is poured into more different packaging units than the average color paint.

<<Table confidential>>

Table 4 - Some details on the 2010 production, split into white and color routings.

2.2.4 The Production Costing Model

PPG AC EMEA uses the SAP Enterprise Resource Planning (ERP) system to control its processes. The principle of Activity Based Costing (ABC) is applied in production and warehousing. Accordingly, overhead cost is linked to activities (rather than directly to products); subsequently, the cost of activities is allocated to products, using an allocation base for each activity (Baker, 1994). The advantage of using ABC is that it leads to better understanding of the costs and its drivers; a major drawback is the limitedness of allocation bases: these generally do not represent the 'true picture' (Hopp and Spearman, 2008).

The VFU factory costs are assigned to activities in the form of eight cost categories (also referred to as performance types): Raw Materials Cost (RM), Fixed Batch Cost (FBC), Packaging Cost (Pack), Fixed Kilo Cost (FKC), Labor Hours Cost (LHC), Fixed Liter Cost (FLC), Machine Hours Cost (MHC), and Other Cost (Other). The latter occasionally encompasses some minor unexpected costs.

2.3 WAREHOUSING

2.3.1 The Warehousing Process

The main activities in warehousing generally are the handling of inbound goods, storage, order picking, and managing the outbound process. Furthermore, there are some value added services taking place in a typical PPG warehouse, such as (re-) labeling and tinting. These processes need support and moreover, the warehouse needs to be kept going. Figure 6 draws a specification of the most common activities within the warehousing process.

Warehouse Activities						
Direct					*Indirect*	
Inbound	Storage	Order picking	Outbound	Value Added Services	Process support/mgmt	General support
Ordering	Storing	Recieving orders	Preparation	Re-packing/labeling	Warehouse management	Plant administration
Recieving	Inventory mgmt	Preparation	Inpection	Tinting	Supply chain planning	General plant supplies
Inspection		Picking	Documentation	Returned goods	Human resources	Plant services
Registering		Wrapping	Labeling		Maintenance	
					Local IT	
					Waste treatment	

Figure 6 – Overview of activities in the warehousing process.

2.3.2 The DCA Warehouse and the Inventory Costing Model

At any given moment, the Amsterdam warehouse (DCA) contains <<>> to <<>>M€ of inventory. On average, <<>> to <<>>M€ of products is processed through the warehouse monthly. About 25% of this value has been supplied by the VFU. All VFU and VFA production is directly shipped to DCA, as well as some of the VFDB production. Figure 7 shows a generalized scheme of the warehousing process at DCA, which is comparable with other Western

European distribution centers. The DCA has the unique feature that many parts of the process are automated though.

At the (un-)loading bays, the pallets are shoved from the truck onto a conveyor belt. At the inbound station, pallets are scanned, weighted and assigned a warehouse location (fully automatically). Using a conveyor belt and automatic forklifts, pallets are stored and extracted from the huge warehouse. Alongside this fully automated process, some stock is handled manually and stored in storage rooms. Pallets are retrieved from storage for order picking. Some value added services take place, for instance when unlabeled tins are labeled with a customer-specific label. Many orders involve putting a combination of different products on one pallet; these pallets are wrapped at packaging stations. The full order should be present at the loading station just before the truck arrives. Appendix C gives a completer overview of this process.

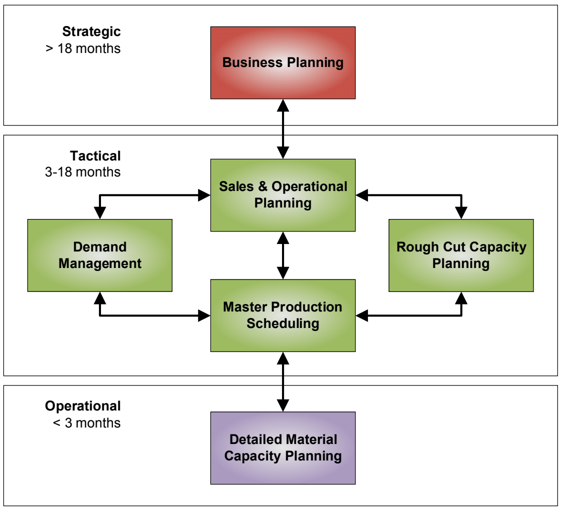


Figure 8 – The planning framework for PPG AC EMEA RNE.

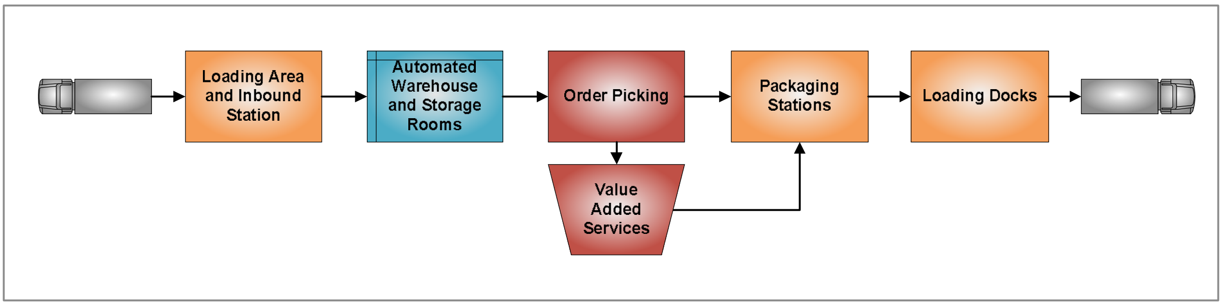


Figure 7 – Simplified DCA warehousing process

Within the warehousing environment, costs are tied to products using ABC allocation. Unlike in the paint factories, there is no system of tariffs whatsoever.

2.4 SUPPLY, DEMAND, AND SUPPLY CHAIN PLANNING

2.4.1 Organizational Aspects

The supply of the vast amount of different products that are marketed by PPG AC EMEA requires a lot of coordination efforts. Each product has its own unique supply and demand patterns. However, these patterns are not stable and may be affected by promotions, new products, competitors, and so forth. For instance, many of the outdoor architectural coatings have a demand peak in the summer months, especially when fine weather occurs during holidays. Inconveniently, those are also the times that the labor capacity in factories is lowest (due to employees having holidays). On the other hand, some products are sold in a stable pattern throughout the year.

To avoid overtime, excess hired labor, and other inefficiencies, this issue needs to be managed. The alignment of the Demand and Supply sides of the organization takes place through the Supply Chain Planning department. This department bridges the gap between the Supply and Demand organizations on a tactical level. The high-level

Business Planning is turned into Operational Plans, from which the specific Production Schedules for each of the factories are deducted.

Within the scope of the Production Schedule, the Planning Departments of the factories are responsible for scheduling the batches on the right routings in an efficient way. Figure 8 summarizes this planning cycle. It is in the factory planning departments that the batch size for specific batches is determined.

2.4.2 The Batch Sizing Process

The batch sizing process currently takes place within each of the AC EMEA factories. The Planning Departments receive various forms of input from several departments, the Master Production Schedule being the most important one.

The Technology Department periodically determines which routings can be applied to produce which products. Not only needs the type of paint that the product contains to be taken into account, but also the average demand and packaging volume. Commonly, a product can be made using two or more routings, often including a low-output and a high-output routing. So, for instance, a given paint type can be made in 3,300kg, 5,500kg, or 12,000kg. This gives the planners some room for making a suitable schedule. When appropriate, multiple filling batches are tied to one production batch. This happens when for example a 2.5l and 5l product with the same paint reach their safety stock levels (nearly) at the same time. Figure 9 provides an overview of the various inputs and outputs involved in the planning process.

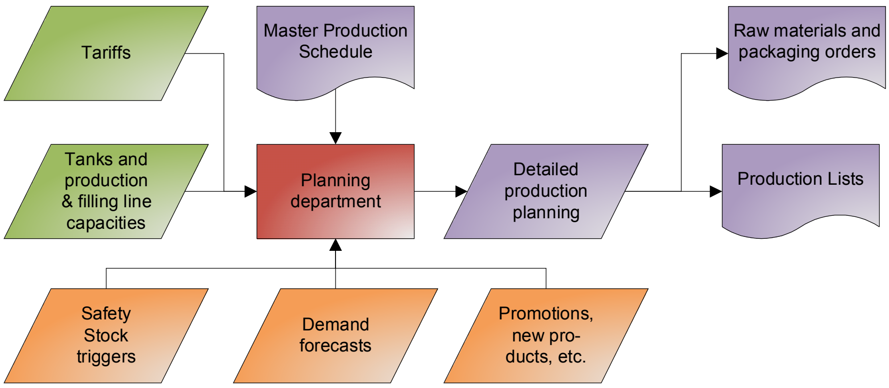


Figure 9 – The current batch sizing process

3 – THEORETICAL FRAMEWORK

This chapter provides some key insights in literature closely related to the topic of this paper. Section 3.1 introduces lot sizing problems. Section 3.2 elaborates on different types of lot sizing models, and Section 3.3 provides detailed information on the Economic Order Quantity model.

3.1 LOT SIZING PROBLEMS

3.1.1 INTRODUCTION TO LOT SIZING AND SCHEDULING

In any industry in which multiple types of non-customized products are made by using common resources such as machines and labor, there is a trade-off between the economies of scale that can be obtained by making large production batches and the disadvantages that the excessive production volumes incur further down the supply chain. More specifically, this amounts to a comparative assessment between low setup cost (inclining towards large production lots) and low holding cost (tending towards small lots). Over the last century, this duality has driven the need for understanding lot sizing and scheduling decisions (Drexl and Kimms, 1997).

Two basic yet very important attributes of lot sizing and scheduling in an industrial environment are:

- The stream of components through a complex production system. Typically, one operation cannot be started until the previous operation in the production process of that certain SKU has finished. Moreover, the processes of all SKUs need to be in tune with each other. Therefore, it is a multi-item problem in a multi-level structure.
- The presence of scarce capacity. Each of the resources in the production environment usually has limited capacity. Therefore, the production activities need to be coordinated in such a way that capacity constraints are not exceeded (Drexl and Kimms, 1997). Utilization rate of the resources is of importance here, as well as downtime due to setups between batches.

Over the last three decades, Lean Manufacturing has changed the landscape of the production sector. It still has its impact on many different industries; however, each industry is affected differently. One of the common effects is the need for suppliers to utilize their production capabilities in such a way that they meet buyer's demand while keeping raw materials and finished goods inventory as low as possible, thus 'leaning' the supply chain by mainly eliminating finished goods inventory (Sarker and Parija, 1994). This tendency also has changed the competitive edge in the paint production industry, where customers (wholesalers and service centers) are now demanding smaller orders, more frequently. Also, as described in Section 1.2.3, the range of different unique products in the paint market is ever widening.

While some suppliers actually succeed in meeting this volatile demand pattern, for example by Just-in-Time production, which fits within the Lean Manufacturing philosophy, it may be the case that others do so by carrying large amounts of finished goods inventory at their distribution centers. This way of meeting demand enables suppliers to maintain their economies of scale in production; albeit by paying the high price of carrying large finished goods inventory (Sarker and Parija, 1994).

3.1.2 Characteristics of Lot Sizing and Scheduling Problems

As introduced in 3.1.1, the problem at hand is a multi-item problem in a multi-level production structure. In order to draw any useful conclusions, these types of problems are often simplified into a more comprehensible structure. In order to facilitate this simplification, assumptions can be made on several parameters of such models. Some of the most common assumptions are on the following parameters (Jans and Degraeve, 2008):

- Single-level or multi-level production process;
- Constant demand or dynamic demand, where dynamic demand can be modeled deterministic or stochastic;
- Whether or not to take capacity constraints into account;
- Continuous or discrete time scale;
- Finite or infinite time horizon;
- Constant or dynamic setup and production times.

Considering these parameters, one can easily understand why there are so many different forms of lot sizing and scheduling models. Some types of lot sizing models are discussed in Section 3.2.

3.2 LOT SIZING MODELS

3.2.1 Evolution of the Lot Sizing Model

The research on lot sizing started with the Economic Order Quantity (EOQ) model. This also is one of the simplest models, assuming a single-level production process, no capacity constraints, and constant demand. It is a single-item, continuous time model with infinite planning horizon, that yields an exact solution (Harris, 1913). Even though the assumptions in the model make its direct use quite restrictive, the model still is useful in many modern applications, albeit that some more effort should be made when interpreting the results.

Other models have evolved from the original EOQ model. The first category that emerged is known as the economic lot scheduling problem (ELSP), as described by Rogers (1958). This is a single-level multi item problem with capacity constraints, under a deterministic dynamic demand assumption. Solving the ELSP is NP-hard, hence driving the solution methods towards heuristics (Drexl and Kimms, 1997). Some variants on the ELSP are the capacitated lot sizing problem (CLSP) and the discrete lot sizing and scheduling problem (DLSP). The CLSP is a large bucket model; hence it assumes that several products can be produced on the same machine in the same time period. A small bucket model on the other hand assumes that a single machine can only produce one type of product in one period. The DLSP can be classified as a small bucket model (Jans and Degraeve, 2008).

The ELSP’s assumptions are still quite drastic. In practice for instance, it is not always reasonable to presume that demand is known, that raw materials are always readily available, or that all setup and production times are fixed. Hence, a stochastic version of the ELSP has been developed, known as the stochastic economic lot scheduling problem (SELSP). The SELSP offers quite a few advantages as compared to the ELSP (Winands et al., 2011); the most important advantage being that the SELSP solution is of a more exact nature. This remedies al kinds of interpretation issues incurred in using the EOQ or ELSP. However, the SELSP has the disadvantage of being quite complex and requiring more advanced programming in order to solve it.

The Wagner-Whitin (WW) problem forms another type of elaboration on the EOQ, by putting more focus on dynamic demand conditions. In the WW problem, the planning period is divided into discrete parts and capacity limits are not included, thus enabling some exact solution approaches.

The modern generation of lot sizing models comprises of more advanced combinations of capacitated and dynamic approaches, and includes the scheduling aspects of lot sizing problems as well (Drexl and Kimms, 1997).

3.2.2 Approaches to Solving Lot Sizing Problems

As introduced in the previous section, solving economic lot sizing problems involves quite some efforts. Many different techniques have been described in literature; Moon et al. (2002) subdivide the tremendous amount of approaches into three main categories:

- Common cycle approach: synchronizing the cycles in which production batches are started makes lot sizing decisions much less complex;
- Basic period approach: setting each product's cycle time equal to a basic period or an integer multiple of a basic period;
- Time-varying lot sizes approach: lot sizes are flexible and safety stocks are re-calculated on each production run.

The common cycle approach is the simplest version of solution methods and uses some bold assumptions. Basic period approach is a lot more complex and NP-hard. Finding a feasible solution often is challenging in this sort of methodology. Nevertheless, it still is a more intuitive way of deriving optimal batch sizes than the time-varying lot sizes approach, in which less far going assumptions are made. The time-varying lot sizes approach does however provide superior solutions as compared to the other two (Karalli and Flowers, 2006).

3.2.3 Extensions to Common Models in Literature

Each batch sizing problem has a rather unique set of parameters, based on the industry context and the assumptions that are made in order to solve the problem. Thereby, many different models have been developed over the ears in order to copy with the various forms of batch sizing problems. This section covers some of the variants that share a common ground with the paint industry's batch sizing issue.

Riddalls and Bennett (2001) study aggregate production-inventory problems and seek out common practical failures to balance setup cost in production with inventory costs of keeping stock. One of the very basic problems seems to be the adequate modeling of batch production costs; it is very hard to determine the true cost of batch sizing decisions. The most distinct recommendation in the paper is that managers should calculate batch sizes based on demand frequently, and make a balanced decision on the size of the batch just before production. Batch sizes should be kept low, but also should be close to or at a divisor of the demand rate. Thereby, the entire supply chain will be smoothened.

Sarker et al. (2008) consider EOQ-like batch sizing models that account for the possibility of rework being done during cycles, as well as after a certain number of cycles. Especially the latter deals with quite some far-going issues and hence provides some useful insights. Nonetheless, the paper stresses the need for flawless production, since rework will always be more expensive than first-time right production. Even though the original paper contained some modeling imperfections, the main conclusions of the paper still hold (Cárdenas-Barrón, 2009).

Groenevelt et al. (1992) study the impact of unreliable manufacturing lines with failure rates and randomly distributed repair times. They use safety stocks in order to meet specified service levels. They show that optimal batch sizes as well as safety stocks increase proportionally with an increase in the unreliability of production. Also, their simulation proves that the cost of slight overinvestment in the maintenance of the production facilities outweighs the cost of slight underinvestment.

Another interesting approach is that of Dobson (1987): taking product-dependent setups into account under a time-varying lot size (TVLS) approach. This is interesting because the product-dependency of setups reflects the true nature of many production environments realistically. This yields an ELSP that can be solved through an optimization heuristic. However, as subsequent research by Shirodkar et al. (2011) shows, this problem cannot be solved in a similar manner for a production environment with sequence-dependent setups (SDS). Nevertheless, SDS is quite common in most industries. Therefore, an ELSP that yields a feasible solution for any given setup sequence has been developed.

A multi-family ELSP (MFELSP) is another variant of the lot sizing problem, in which product families share common setup costs, while on the other hand each SKU also has its own unique setup. Karalli and Flowers (2006) introduce a MFELSP with safety stocks in their article, concluding that inclusion of the safety stocks in the problem yields an approximate cost saving of 10%.

3.3 THE ECONOMIC ORDER QUANTITY MODEL

3.3.1 General Description

As derived by Harris (1913), the EOQ model is one of the very basics of operations management. The EOQ model describes the total cost of production with the lot size as a control variable. Defining D to be the demand rate (units/year), c the production cost (EUR/unit), A the setup cost to produce a lot (EUR), h the holding cost (EUR/item/year), and Q to be the lot size (units), the total cost per year is denoted by:

$$Y(Q) = \frac{hQ}{2} + \frac{AD}{Q} + cD \qquad (1).$$

Thus, total cost equals the sum of respectively yearly holding, setup, and production cost. The standard version of the model assumes that production is instantaneous, delivery is immediate, demand is deterministic and constant over time, production runs incur a fixed setup cost, and products can be analyzed individually (Harris, 1913). In case the holding cost exists entirely of interest on money tied up in inventory, then $h = ic$, with i being the annual interest rate. Diagram 1 shows an example of how the EOQ model's components relate to each other.

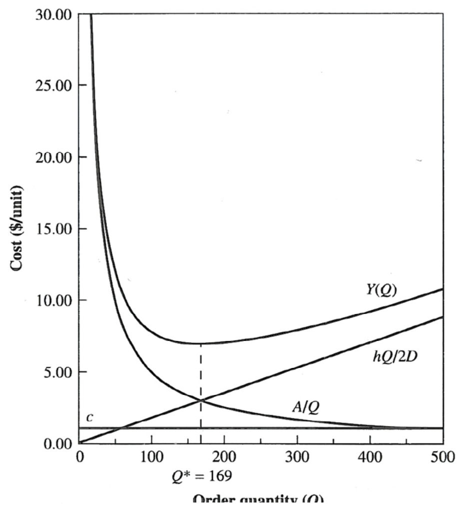


Diagram 1 – The EOQ model components.

Taking the derivative of $Y(Q)$, setting the result equal to zero, and solving for Q, yields the lot size that minimizes $T(Q)$ in function (1), also known as the EOQ:

$$Q^* = \sqrt{\frac{2AD}{h}} \qquad (2).$$

3.3.2 Implications of the EOQ Model

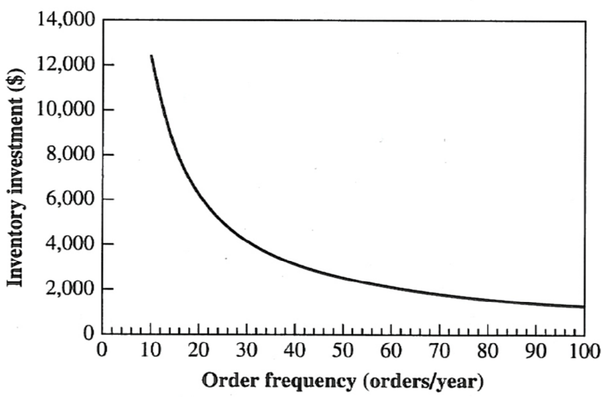


Diagram 2 – Inventory investment and order frequency.

The EOQ model provides us with two key insights (Hopp and Spearman, 2008). The first is that there is a tradeoff between batch size and inventory. Plotting inventory investment (EUR) as a function of the replenishment frequency (orders/year) results in a concave pattern similar to the example that Diagram 2 displays. The second insight is that the sum of holding and setup costs is rather insensitive to lot size. This is also visible in Diagram 1, where total costs range from 7 to 8 for a lot size between 96 and 306.

In other words: from a theoretical point of view, total cost are not heavily affected by a change in batch size as the increasing setup costs will be cancelled out by the decreasing holding costs. Note that this is generally not the case for values of Q far from the optimum.

3.3.3 EOQ Model Assumptions

In order for the EOQ model to work, six main assumptions have been made. These do not necessarily make the model less valuable than other models, since many models are based on similar assumptions. Nonetheless, these assumptions should be borne in mind when interpreting the model's results. Hopp and Spearman (2008) specify the assumptions of the original model as:

- Instantaneous production: no constraints, no lot break-ups;
- Immediate delivery: no lag between production and availability;
- Deterministic demand: quantity and timing of demand are known;
- Constant demand;
- Setup cost per batch is fixed: for instance not dependent on product type;
- Products can be analyzed as mutually independent entities.

Some of these assumptions are more extreme than others for the paint production process. When building a model, it will be possible to relax one or more of these assumptions.

4 – ANALYSIS

Chapters 2 and 3 have clarified the problem context and relevant literature. Now we want to see how a batch sizing trade-off would preferably be used in practice, facilitating an inventory reduction. Section 4.1 outlines the full trade-off involved in the batch sizing process, which would ideally be taken into account for every batch that is planned. After Section 4.1 has formulated this desired situation, Sections 4.2 and 4.3 focus on differences between this desired situation and the current situation; Section 4.2 looks into the operating cost aspects of batch sizing and how this drives the current batch size decision making. Section 4.3 holds an analysis of the batch size-inventory cost trade-off. These two sections cover both sides of the desired trade-off discussed in Section 4.1. This balance lies at the very core of determining the most adequate batch size. Therefore, this chapter pays considerable attention to quantifying the relevant aspects in operating cost and inventory cost that drive both sides of this trade-off.

4.1 THE BATCH SIZE TRADE-OFF

It is generally assumed that batch size reduction leads to more complexity and thereby a cost increase. The idea that producing in large quantities is cheap certainly has logic to it. However, producing large quantities means less flexibility in production, because it takes more time per batch and does not offer much room for rescheduling. This lack of flexibility has to be compensated with more inventories: safety stock as well as more ‘normal’ stock to bridge the time between two subsequent batches. Because it is very expensive to have more inventories, this pushes the company towards more dependence on forecasts and planning. Also, this dependence, combined with the other factors, causes a stock-out to be more probable to occur.

Producing in smaller batches solves many of these problems. However, making smaller batches means more frequent setups, and that causes additional production cost. Also, this will cause more setup time on production lines and therefore seize much capacity in the current production setting. Figure 10 displays this trade-off, showing both possible scenarios. Obviously, there is a huge downside to having the excess stock that is needed when producing large batches. But also a big disadvantage will be incurred when raising the frequency of setups in the production and filling lines.

The antithesis between the two scenarios illustrated in Figure 10 raises the question where the balance between these two can be found. And furthermore, under what circumstances it is economically feasible to produce small batches. These circumstances are different for each SKU; because every SKU has its own -often unique- demand pattern, safety stock, forecasts, production time, setup times, production planning properties (routings), holding costs, et cetera.

Even when just a few of the most important of these aspects are taken into account, it will be very hard to assess each SKU’s individual batch size trade-off optimum with an intuitive approach. Therefore, a more formalized method is required. Given all the inputs, the Planning Department should be supported in their decision making in a more exact manner, rather than relying on periodically updated general planning ‘rules’, such as routings and production quantities. An obvious option is to enhance the usual SAP outputs used with up-to-date optimal production quantities, which take the entire batch sizing trade-off into account. Also, for instance by means of a pilot, a less complex tool can be developed to do this trade-off alongside the usual systems.

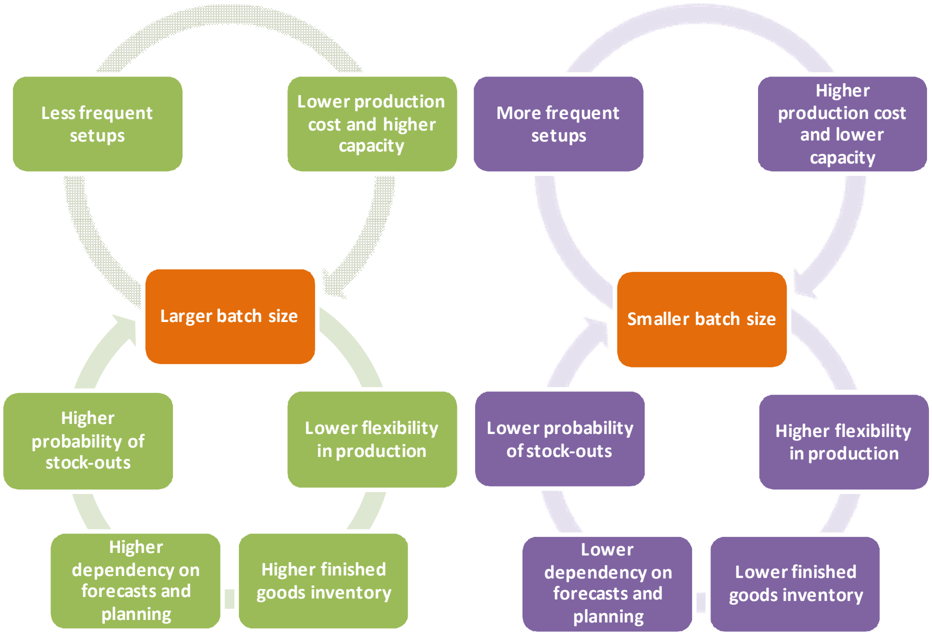


Figure 10 – Two batch size alteration scenarios and their effects.

4.2 BATCH SIZES AND OPERATIONAL COST

4.2.1 Operations Costing

As introduced in Section 1.3.2 and explained in Section 2.2.4, seven different tariffs are used in the costing model (Labor Hour Cost, Fixed Batch Cost, et cetera). For every factory, all tariffs are updated yearly, mainly based on last year's results and some assumptions about the foreseeable future, such as developments in salaries. On a monthly basis, the number of hours, batches, kilos, and liters are determined. Figure 11 shows the 2010 (entire year) values for the VFU, along with each of the tariffs. These two tables multiplied lead to the budgets for 2010 on each of the tariffs. Also, the Raw Materials and Packaging budgets are calculated based on the Operational Planning.

<<Figure confidential>>

Figure 11 – Planning of activities, tariffs, and budgets for the VFU in 2010.

All cost incurred in production are allocated to each of the tariffs through Activity Based Costing. Every month, these results are matched with the budgets on the tariffs, leading to a coverage percentage. It is this coverage that is the most important tool for plant management to make sure that production costs are well-controlled. When for instance more labor hours than planned are spent on a series of batches, this means that the coverage percentage will go up. This then needs to be compensated with labor time savings on other batches. Appendix E shows a more detailed study of the tariff system.

From a broader perspective, this coverage-ratio system has some potential flaws. Primarily, it will lead to production planning decisions that would not have been made otherwise. When coverage ratios for a certain year are high, there will be a tendency to produce a lot of white paint batches in December; this will bring down coverage, because both cost per kilo and LHC/MHC are lower. However, this tendency to comply with tariffs and planning may cause much additional inventory, which is quite expensive. This trade-off is not accounted for.

More importantly, the current tariffs system does not facilitate a change in batch size and frequency. Because tariffs are not updated throughout the year, a change in production policy to produce more and smaller batches would devastate coverage ratios and is therefore not feasible. For example, the total sum of expenses that is allocated to Fixed Batch Cost can be divided over many more batches, resulting in a significantly lower tariff.

4.2.2 Data Analysis VFU

In this section, some relevant and notable patterns that have been found by studying various data files (retrieved from SAP) are pointed out. First of all, production volumes, batch sizes et cetera are compared for the different brands that are produced in the VFU. Second, this section studies the relationship between batch size and cost, followed by an analysis of the distribution of batch sizes and production volumes. This provides key insights in how production and batch sizing currently is put into practice and what its internal effects are.

PRODUCTION PORTFOLIO

When looking at the different brands, the most obvious difference between them lies in their annual production volumes. Just the Sigma Coatings and Histor brands together cover <<>>% of total volume; <<>>% of the produced volume is in the top 10 brands. Not surprisingly, batch sizes differ quite drastically among brands. However, the top brands show quite comparable results, with filling batch sizes roughly between <<>> and <<>>L.

Appendix F gives an overview of the 2010 production data for all brands produced in the VFU. Because every paint factory produces many brands in a similar fashion, we think it is reasonable to assume that there is a similar Pareto-like pattern in other factories' production volumes as well.

BATCH SIZES AND OPERATIONAL COST

One of the central issues in this thesis is the relationship between batch sizes and operating cost. Logically, one would expect total cost per kilogram of paint to be inversely proportional to batch size, as the left hand side of Diagram 3 shows. This would be mainly due to the increase in setup cost associated with smaller batch sizes and the economy of scale that is obtained by producing large batches.

The right hand side of Diagram 3 displays the actual patterns in costing for both white and color paints. The blue line indicates the average for white-routed paints and the red line for color-routed SKUs. These patterns are slightly different than the expected pattern; most remarkably, the actual patterns are upward sloping at values above the optimum batch size. This difference between the graphs can be explained by the fact that each production routing has its own optimal batch volumes, under which it performs more efficiently. The data shows what batch sizes are optimal under the current production facilities as well as the costing model. Therefore, there will be higher cost for lower- as well as higher-than-optimal batch sizes.

Also, the fact that all different white and color SKUs on all different production and filling lines are combined into two plotted trends most probably makes the trend lines smoother and more averaged than they would be for a single SKU. If one would be able to look at a single SKU and be able to alter its batch size regardless of the constraints that are raised by the production facilities, then likely a diagram resembling the shape of the expected pattern in Diagram 3 would appear.

Not surprisingly, the data confirms that the optimum for white paint lies on a higher batch volume of about an average of 18,000kg, whereas the optimal color production volume equals almost half of that: 9,000kg. This is due to the fact that white paint is produced, filled, and sold in larger volumes. Second, the colored paint costing line is more sensitive to a change in batch size, which is the case because there are less different production lines and HALB-FERT combinations for color paints; these enable the white paints to be produced economically at many different volumes. A more detailed version of the right hand side of Diagram 3 can be found in Appendix G.

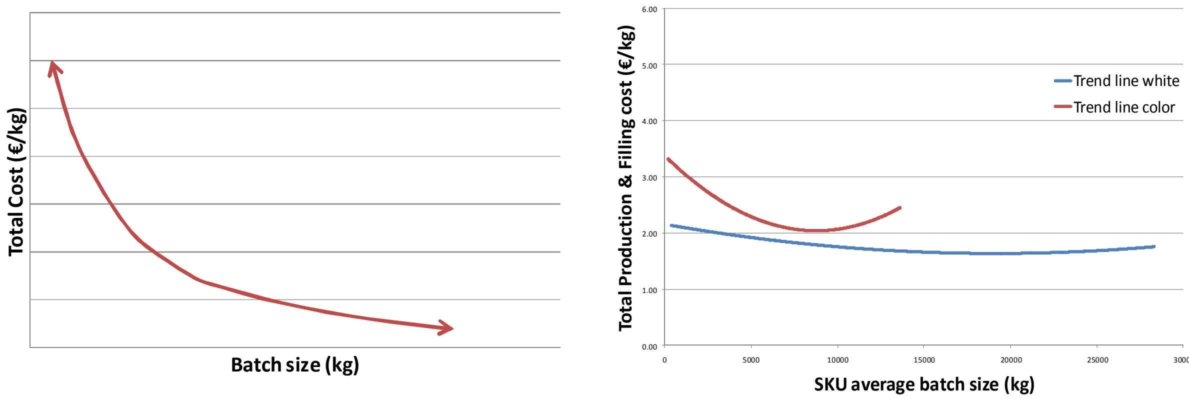


Diagram 3 – Left graph: expected cost versus batch size pattern. Right graph: actual cost patterns according to 2010 VFU data.

BATCH SIZES, BATCHES, AND PRODUCTION VOLUMES

Another aspect that requires analysis is the relationship between the number of batches and production volumes. Further data has been studied to assess to what extent the production volume is produced in large and small batches, and whether or not there are significant differences between white and color routed paints. Appendix G gives a graphical overview of the pattern in which production volumes are spread over batch sizes.

From Appendix G, it can be seen that the five highest white paint batch size classes account for 78% of production volume, but just 53% of the number of batches. On the other hand, the bottom five classes contribute just 22% of production volume, while they cover 47% of batches. Clearly, there is a lot of production in the high-volume, batch sizes, which are produced at a low frequency.

For color paints, this pattern is quite comparable. The 6 largest batch size classes account for 41% of production volume, while they cover just 15% of batches. The four classes with smallest batch sizes have 59% of the volume and 85% of batches. So while there is relatively more volume in the smaller batch classes for color paints, there also is quite some high-volume, low frequency production.

So considering these patterns, we conclude that there is a tendency in production towards producing some paints in small quantities while on the other hand a large number of paints are produced in very large quantities. This results in a large proportion of the produced volume accounting for just a small number of the batches and vice versa. This should be borne in mind for decision making in the batch size trade-off.

4.2.3 The Batch Size Force Field

As stated in Section 1.2.3 and underlined for the VFU factory in Section 4.2.2, there is a strong tendency within the AC EMEA factories towards the production of large batches. We have found two main forces driving this phenomenon: narrow optimization focus and complexity avoidance. These two factors combined seem to cause the local planning and scheduling optimizations in factories to yield low-frequency, high-volume batches.

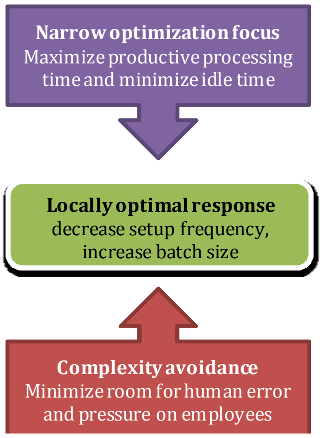


Figure 12 – The force field regarding batch size optimization

Figure 12 gives a schematic overview of these drivers. The first, being the most important driver, is mainly caused by the costing model, which was described in the previous section, but maybe even more by a traditional sense of optimality by maximizing capacity utilization. Also, the performance measurements that are in place on the factory floor tend to stimulate this behavior, because they focus on maximizing up-time. Consequently, large batches are more or less unavoidable in order to reach the output-based goals. The second driver should nonetheless also be taken into account, for complexity avoidance may well be a very important underlying motivation for the current low setup frequencies.

These factors strengthen each other. Because of the coverage-ratio mechanism within the costing model and the performance measurements on productive processing time, combined with some complexity avoidance, employees are forced to make even larger batches in case unexpected events cut down output. A final important aspect to bear in mind is that factories have been subject to inflexible high-volume production over the last decades. This means that the industrial assets are not aligned to cope with a production scheme that requires more frequent setups, and moreover, employees may not be adequately proficient in working in a more flexible environment.

4.2.4 Defining Setup Cost

Setup cost comprises of all cost incurred in switching from one batch to the next on a production line. In Section 4.2.2, the variations in costing for different batch sizes have been discussed. Clearly, an economy of scale is gained when producing large batches, especially under the current costing model. It is, however, far more relevant what the ‘real’ effects of batch size decisions are, rather than how it works out on paper. Setup costs are an important part of this equation.

Therefore, determining what this setup cost amounts to is of vital importance. First of all, there are actually two kinds of setups in the factories: one for production batches and one for filling batches. A distinction needs to be made between these two types of batch setups, especially given the fact that the ratio between the number of production and filling batches is not fixed. Also, there are significant differences between color and white paint setups.

A production setup includes administrative activities, order picking, and cleaning the machinery after a batch is produced. A filling setup includes collecting packaging materials, pigging, aligning multiple parts of the filling machinery, and cleaning. There are some additional setup-like activities, such as cleaning filters, but I presume that these are more of a periodic nature, and as such not directly influenced by the batch frequency or size.

<<Table confidential>>

Table 5 - Setup cost for all different types of setups in the VFU

Furthermore, there is an extra setup involved in preparing the labeling line for a new package size and form. Filling setups take a lot more time when a can or bucket with other dimensions than that of the previous batch is to be processed. This is due to the fact that the labeling line needs to be aligned to the dimensions of the bucket or tin, just like the filling line. Table 5 shows an estimate of the setup cost for all batch and paint types. Consequently, each batch has an own mix of setup costs, depending on the kind of paint produced and filled as well as the preceding batch's packaging dimensions.

4.3 BATCH SIZING AND INVENTORY COST

4.3.1 DATA ANALYSIS DCA

In this section, a data set of DCA inventories is subject to analysis, with a focus on inventory supplied by the VFU and the effect of batch sizing on inventory developments. But first, a general overview of 2010 stocks is given.

INVENTORY ANALYSIS

Analyzing the inventory levels in the DCA warehouse from February 2010 to February 2011, one of the most obvious patterns to study is the average inventory levels over the year. When divided into SKU-types, this yields the pattern that Diagram 4 displays. The most noticeable feature of this pattern is the high volume of B-articles and discontinued SKUs on stock. In all diagrams presented in this section, the inventory level is shown as number of items (tins/buckets of paint) on inventory within that category.

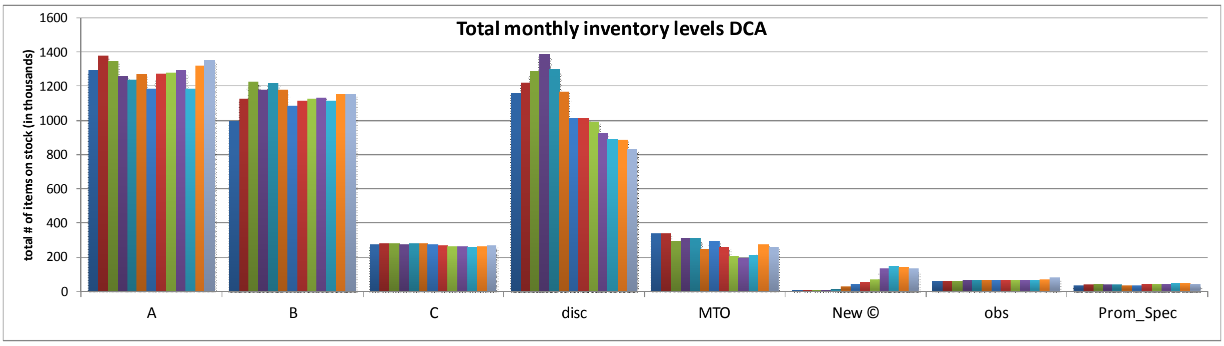


Diagram 4 – Overview of monthly 2010 DCA inventory levels for all SKU types.

When divided by the number of SKUs per type, this yields the average monthly inventory levels as plotted in Diagram 5. When comparing the diagrams, note that the total inventory of B-articles is quite high, but the average is relatively lower. This is simply due to the fact that there are many different B-SKUs. This goes to an even further extent for the discontinued SKUs. Promotional SKUs, on the other hand, have a high average volume but are low in total volume because their number is quite limited.

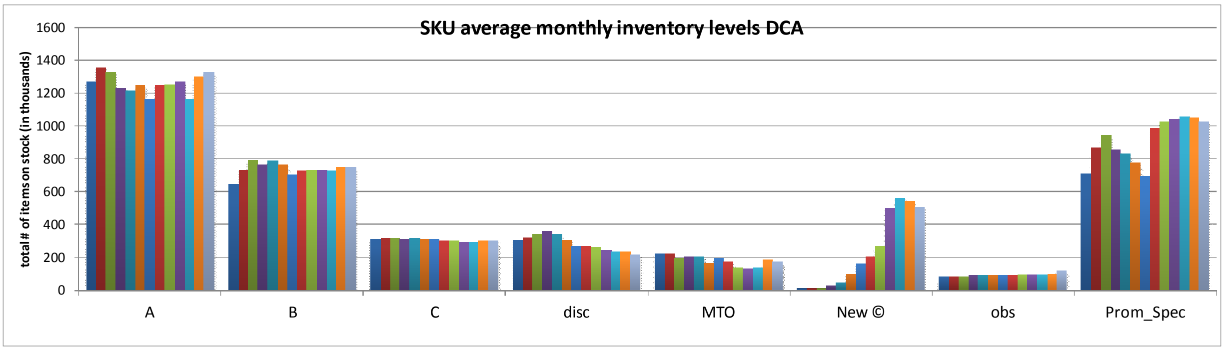
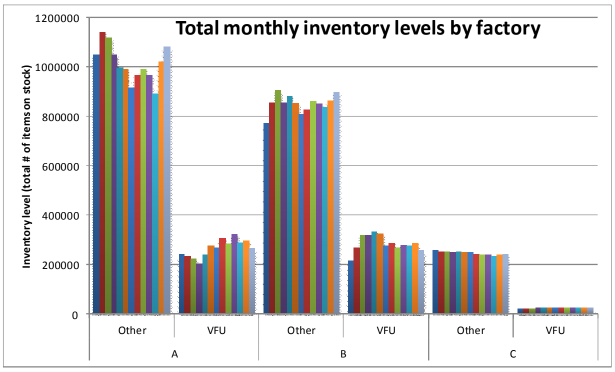


Diagram 5 – Overview of average monthly 2010 DCA inventory levels for all SKU types.

Another interesting characteristic can be seen when comparing the proportion of inventory that has been supplied by the VFU with the VFA and VFdB supply. This comparison has been graphed for A-, B-, and C-SKUs in Diagram 6.The average inventory volume per SKU seems to be stable between the different factories, yet slightly lower for VFU-supplied A-SKUs. Total inventory supplied by the VFU ranges from approximately 1/5 for A-, to 1/4 for B-, and 1/10 for C-SKUs.



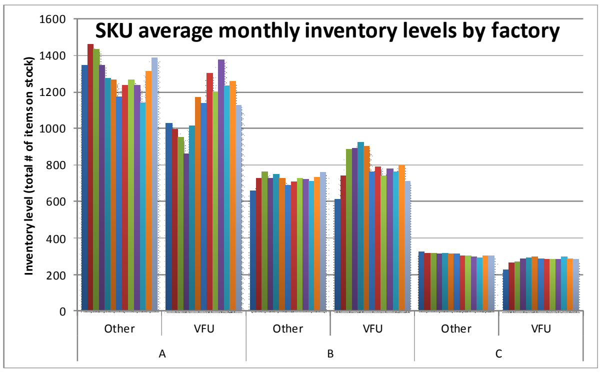


Diagram 6 – Total and average DCA inventory levels, subdivided into VFU and non-VFU supplied volumes.

BATCH SIZES AND INVENTORY LEVELS

When studying the average batch sizes for VFU SKUs and their corresponding average inventory levels in the DCA, a clear pattern of correlation emerges. Diagram 7 contains a plot of this pattern. High-volume production obviously causes high inventory levels, and as can be seen this also applies to the VFU-DCA setting.

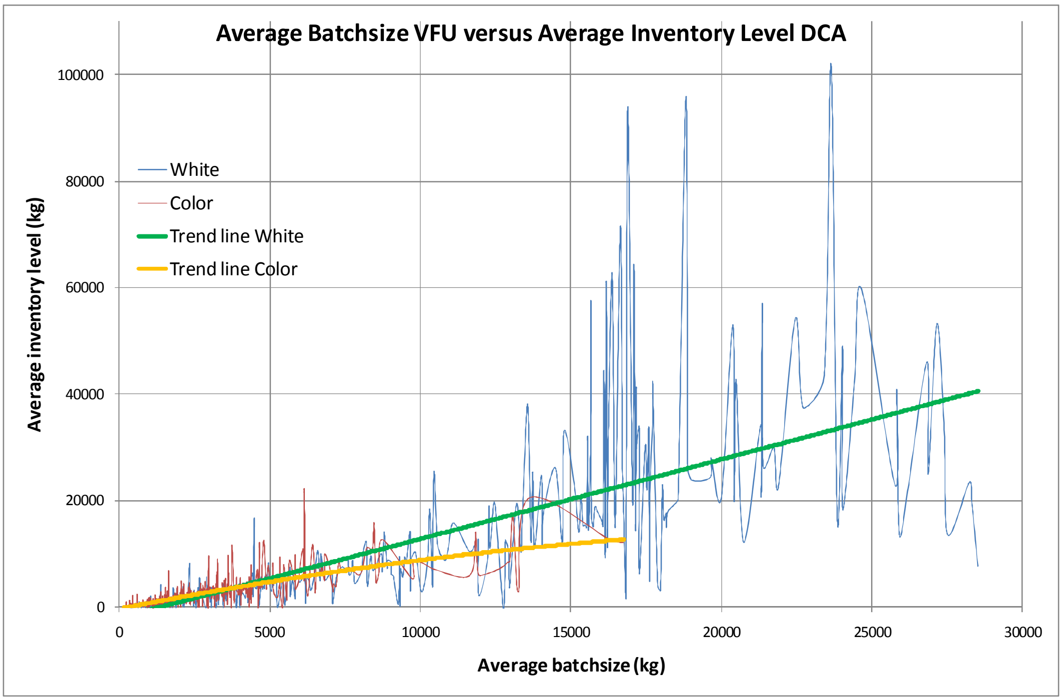


Diagram 7 – Average inventory levels and average batch sizes for all VFU SKUs.

4.3.2 Defining Inventory Cost

As briefly addressed in Section 2.2.4, the inventory costs are allocated to products through Activity Based Costing. Inventory cost encompasses all cost of having goods in stock and is usually expressed as a percentage of inventory value. Important aspects are warehousing cost, cost of capital, depreciation, insurance, and obsolescence. Using the inventory cost percentage, it is quite easy to establish a good indication of the cost of putting items on stock when producing larger batches or the saving incurred in producing a smaller batch.

Table 6 specifies each of the inventory cost drivers as well as their respective percentages. Warehousing cost (upkeep, employees et cetera), cost for indirect warehousing processes (such as management), and obsolescence cost have been deducted from various internal data sources stating the actual expenses for 2010.

Cost of capital can be defined as the opportunity cost of investing in an asset relative to the expected return on assets with similar risk. So in this context, it is the money that could have been made with the value that is now being consumed by inventory. It is rather difficult to determine the Weighted Average Cost of Capital (WACC) for a company, especially given the fact that it fluctuates and depends on quite a lot of factors. The average WACC for US companies roughly is 9%, so that is the percentage we have assumed to apply to PPG Industries as well. Also, the percentages for depreciation and insurance have been estimated based on literature.

<<Table confidential>>

Table 6 – Inventory cost drivers and percentages for DCA in 2010

Altogether, this adds up to a <<>>% cost of inventory rate. This is rather high as compared to the theoretical rates in Appendix B, due to the high cost of warehousing in the DCA. Because an overestimation will affect the trade-off towards optimality by saving inventory, the conclusions of the model will be stronger if the percentage is a bit too low rather than too high. For further analysis, we will therefore use a VFU inventory rate of <<>>%. The underlying assumption is that the cost of operating the DCA warehouse will not be fully correlated with inventory levels in the short run; an impact of just $1/3$ of warehousing cost can be reached.

5 – THE BATCH SIZING MODEL

Chapter 4 discussed the full batch sizing trade-off. The two major levers steering this trade-off are setup costs and inventory cost; the analysis of Chapter 4 quantifies both. As has been pointed out, this balance is very delicate and will not be easily assessed intuitively. Hence, even a simple model will have an added value in understanding the batch sizing dynamics to a fuller extent.

To explain which batch sizes are optimal in terms of profitability, a model has been constructed, as described in Section 5.1. This will yield implications for optimizing the batch sizing trade-off to increase profitability by reducing inventory. Section 5.2 provides insights into the model results, which contribute to the final conclusions presented in Chapter 6.

5.1 THE BATCH SIZE OPTIMIZATION MODEL

5.1.1 MODEL CONSTRUCTION

The key added value of the model is to make the effects of batch size decisions measurable. Therefore, both the setup and the inventory cost need to be incorporated. As introduced in Chapter 2, there are important distinctions between production and filling batches, and they can be matched in multiple ways. So not only does the model need to optimize the number of batches per SKU, but this also needs to be aligned with the (larger) production batches of that particular paint type. Figure 13 briefly summarizes the way the model works.

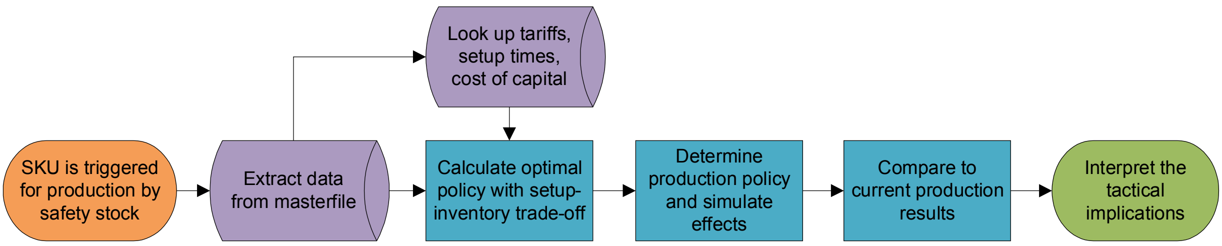


Figure 13 – Schematic model layout.

The model first calculates an optimal production quantity based on the EOQ formula discussed in Chapter 3; not only for the SKU that has triggered the production batch, but also for the other SKUs from the same HALB. It gathers the needed data from the data master file attached to the model. Then it will model the effects of producing this optimal batch size on inventory development, and find the production quantity that yields minimum total cost on production and inventory.

To achieve this, we made a cycle-based model. As presented in Chapter 2, if a certain HALB (semi-manufactured product) batch is started, it is efficient to make enough of this paint so that all FERTs (SKUs) that need to be filled can actually be filled from this same batch. With a lead time of 3/4 month, this makes 16 of these cycles in a year. Therefore, the cyclic model consists of a minimum of 1 and a maximum of 16 cycles in a year.

Finally, a reality check needs to be done in order to see whether the optimum for this specific SKU lies at an acceptable batch size according to production constraints. This interpretation step will also be conducted in Section 5.2, which presents and interprets model results.

5.1.2 Assumptions and Boundaries

In order to make the model both realistic and comprehensible, we need some assumptions on various factors, as well as a choice of what to include or leave out of the model. The list below depicts the most important assumptions and boundaries of the model:

- Safety stocks remain fixed. The reason for this is that optimizing these values lies outside the scope of this research and is already being included in another project (Smartops; Steve Jackson). However, safety stocks can be lowered when batch sizes are reduced. This potentially beneficial side-effect should well be borne in mind;
- Fixed Batch Cost can be ignored in the trade-off. It is all about setups and inventories; the FBC will just be spread out over the number of batches produced and therefore will not be part of it;
- Made-to-order, Discontinued, Obsolete, New, and Promotional SKUs are not included, due to their production planning depending on other factors than the A, B, and C SKUs;
- Demand will be constant over the year. This is not a realistic assumption, but due to the limited level of detail in the data set it was inevitable to do so;
- The stocks of January 1st 2010 have been used as a starting point for the model;
- Capacity constraints are left out of the model. These are relevant, but should be taken into account on a more operational level. Including a capacity model would heavily increase the complexity of the model.

5.2 MODEL RESULTS

5.2.1 Sample of Results

When a specific SKU is selected in the top sheet of the Excel file that contains the model, all sheets automatically present all relevant characteristics of that SKU and the calculation results for the batch size optimization. This section presents the most relevant optimization results for a selection of nine different SKUs, and considers both the 'plain' optimization and the cyclic optimization. Furthermore, this section compares these optimization results with the historical values from the data set. Also, we present the savings that are obtained by optimization.

In order to get a good sample of SKUs, we have selected three products from each product category. The first SKU selected from the category of A-products (high volume, high throughput) is among the most frequently produced products in the factory. The last SKU selected from the C-category (low volume, low throughput) is one of the least produced products from the portfolio. By doing so, we obtain a representative range of nine products.

This section presents Tables 7-11; each displays the following parameters:

- Product: name of the SKU;
- Category: type of SKU;
- Demand: demand from customers in a year (in kg);
- Production: quantity produced in a year (in kg);
- # of batches: number of batches in a year;
- Avg. batch size: average quantity produced per batch (in kg);
- HALB setup cost: cost to set up the batch of semi-manufactured product (in €);
- FERT setup cost: cost to set up the batch for filling the SKU (in €);
- Inventory cost: cost to hold the inventory of that FERT during a year;
- Saving (Table 8 and 9): saving of the model output as compared to the historical values in Table 7.

Table 7 shows the historical data on each of the nine products. The most remarkable observation is that the first product in Category A has been produced very frequently, but its batch size is relatively small. This can be explained by looking at the total number of other FERTs that this HALB comprises of. There are 16 other FERTs with the same paint. To keep all those high-demand SKUs on stock, a batch is started very frequently, resulting in a low average batch size for this product. So from an inventory point of view, this SKU is produced quite efficiently.

Historical data								
Product	**Category**	Demand (kg)	Production (kg)	# of batches	Avg.batch size (kg)	HALB setup cost	FERT setup cost	Inventory cost
1	**A**	2,285,537	2,204,163	117	18,839	€ 8,043	€ 6,031	€ 9,582
2	**A**	305,832	300,105	15	20,007	€ 2,658	€ 773	€ 4,288
3	**A**	48,307	56,080	8	7,010	€ 315	€ 412	€ 1,463
4	**B**	499,591	453,348	28	16,191	€ 6,540	€ 1,443	€ 7,782
5	**B**	50,003	53,577	9	5,953	€ 9,617	€ 464	€ 358
6	**B**	5,238	6,440	5	1,288	€ 1,038	€ 270	€ 690
7	**C**	6,018	6,832	2	3,416	€ 816	€ 108	€ 458
8	**C**	3,018	2,336	4	584	€ 350	€ 206	€ 153
9	**C**	194	1,544	1	1,544	€ 74	€ 54	€ 534

Table 7 – Historical results for the selection of products.

Table 8 shows the model outputs for the plain optimization of the batch sizes: finding the optimum between production and inventory cost with the EOQ method. For eight out of nine products, batch size should be decreased according to the model. For these SKUs, there will be a saving by doing so. Some of the savings seem small, but in the perspective of a very wide product range of 1100 SKUs, the combined savings will be high.

SKU 8 yields an increased batch size and a negative saving – this is caused by the fact that the historical data include a production quantity that is much lower than demand (the next batch probably took place just after the year ended). As stated, the first A-product is produced very frequently; this optimization indicates that the savings in setup cost actually outweigh the increase in inventory cost when batch size is increased.

Model output (plain)									
Product	**Category**	Demand (kg)	Production (kg)	# of batches	Avg.batch size (kg)	HALB setup cost	FERT setup cost	Inventory cost	**Saving**
1	**A**	2,285,537	2,271,646	82	27,703	€ 2,623	€ 2,999	€ 1,363	**€ 16,671**
2	**A**	305,832	300,564	36	8,349	€ 2,343	€ 1,681	€ 2,366	**€ 1,329**
3	**A**	48,307	47,055	15	3,137	€ 420	€ 407	€ 586	**€ 777**
4	**B**	499,591	496,960	40	12,424	€ 2,483	€ 7,005	€ 1,808	**€ 4,469**
5	**B**	50,003	47,920	10	4,792	€ 1,259	€ 3,274	€ 137	**€ 5,769**
6	**B**	5,238	4,788	4	1,197	€ 445	€ 509	€ 150	**€ 894**
7	**C**	6,018	4,632	3	1,544	€ 445	€ 433	€ 64	**€ 440**
8	**C**	3,018	2,646	3	882	€ 315	€ 768	€ 50	**€ -424**
9	**C**	194	194	1	194	€ 74	€ 25	€ 21	**€ 542**

Table 8 – Optimization results for the selection of products.

Table 9 displays the model outputs for the cyclic optimization of the batch sizes: finding the optimum between production and inventory cost with the EOQ method and combining FERTs from the same HALB in 1 to 16 cycles. This constraint of 16 cycles yields an infeasible average batch size for the first product, because the maximum tank capacity in the factory lies around 30,000kg. Therefore, this saving is artificial; the factory should make 76 batches of 30,000kg.

This maximum number of cycles constrains all three products in the A -category. Also, savings from the model for these and other A-category products are relatively low, primarily because they are already produced at a high frequency and furthermore they usually share their HALB with many other SKUs. The cyclic model therefore does not yield very good results for the A-category. The B- and C-categories yield reasonable savings, and the results are slightly better than that of the plain model. This is primarily due to the fact that multiple SKUs are filled from one batch of HALB, by coupling them in cycles.

Model output (cyclic)									
Product	**Category**	Demand (kg)	Production (kg)	# of batches	Avg.batch size (kg)	HALB setup cost	FERT setup cost	Inventory cost	**Saving**
1	**A**	2,285,537	2,266,096	16	141,631	€ 560	€ 825	€ 0	**€ 22,271**
2	**A**	305,832	295,904	16	18,494	€ 560	€ 825	€ 2,285	**€ 4,049**
3	**A**	48,307	50,544	16	3,159	€ 560	€ 825	€ 761	**€ 44**
4	**B**	499,591	455,850	15	30,390	€ 560	€ 773	€ 1,216	**€ 13,216**
5	**B**	50,003	47,920	10	4,792	€ 560	€ 515	€ 172	**€ 9,192**
6	**B**	5,238	7,182	6	1,197	€ 668	€ 325	€ 219	**€ 786**
7	**C**	6,018	4,632	3	1,544	€ 593	€ 162	€ 61	**€ 566**
8	**C**	3,018	2,646	3	882	€ 385	€ 155	€ 29	**€ 140**
9	**C**	194	194	1	194	€ 74	€ 54	€ 57	**€ 477**

Table 9 – Cyclic optimization results for the selection of products.

5.2.2 Patterns in Output

One of the most important findings is that the model yields no very unrealistic values. Its results therefore seem to be promising, and moreover, they match our expectations based on literature. Nevertheless, some interpretation of each optimization is needed, because each SKU's unique properties are of great importance for understanding the feasibility of the saving.

The three main patterns in a sample of model outputs are:

1) Batch sizes generally decrease and frequency of batches increase as compared to the current situation;
2) The inventory reduction almost always outweighs production cost increase, yet this saving can be insignificantly low;
3) Number of SKUs filled from one production batch goes up; this is a very straightforward way of decreasing setup cost by bundling FERTs form one HALB.

These results tally with our expectations. Therefore, we assume that the dynamics in the model do their job appropriately. Although each SKU yields different outputs, it is also clear that most of the C-articles, which are usually produced in considerable minimum quantities with long intervals between succeeding batches, can be produced in smaller quantities, resulting in a relatively large saving. On the other hand, the A-articles generally could be produced in slightly smaller batches at a small increase in batch frequency, yielding a small saving per kilogram.

5.3 MODEL SENSITIVITY

Setup and inventory cost are the most important parameters of the model, because they form the very basis of the batch sizing trade-off. Therefore, a systematic over- or underestimation of the true value of those parameters may affect the model's results in such a way, that the output is biased. The difficulty is that we cannot verify directly whether the assumptions on these parameters are correct. Therefore, this section presents a sensitivity analysis.

In order to see the impact of a wrong estimation of the setup and inventory cost, we want to see what happens with the model outputs when setup costs are increased or decreased. From the model, we get small differences in optimization results when parameters are adjusted marginally. To draw very strong conclusions on this matter, this section shows what happens when the parameters are adjusted drastically.

Table 10 shows the most relevant outputs for a 50% reduction on setup cost, the default scenario (as in Section 5.2.1), and a gain in setup cost of 50%. Table 11 does the same, but now for inventory cost adjustments.

		Setup cost - 50%				Default settings				Setup cost + 50%			
Product	Category	*Plain model*		*Cyclic model*		*Plain model*		*Cyclic model*		*Plain model*		*Cyclic model*	
		# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings
1	A	116	€ 11,830	16	€ 15,927	82	€ 16,671	16	€ 22,271	67	€ 21,932	16	€ 28,617
2	A	51	€ 1,184	16	€ 3,026	36	€ 1,329	16	€ 4,049	29	€ 1,795	16	€ 5,061
3	A	21	€ 763	16	€ 412	15	€ 777	16	€ 44	12	€ 937	13	€ 46
4	B	56	€ 4,195	15	€ 9,891	40	€ 4,469	15	€ 13,216	32	€ 5,625	15	€ 16,541
5	B	14	€ 2,432	14	€ 4,514	10	€ 5,769	10	€ 9,192	8	€ 9,451	8	€ 13,876
6	B	6	€ 596	7	€ 654	4	€ 894	6	€ 786	3	€ 1,309	5	€ 1,037
7	C	5	€ 189	4	€ 328	3	€ 440	3	€ 566	3	€ 654	2	€ 739
8	C	4	€ -337	4	€ 102	3	€ -424	3	€ 140	2	€ -445	3	€ 151
9	C	1	€ 526	1	€ 405	1	€ 542	1	€ 477	0	€ 577	1	€ 453

Table 10 – Model outputs for altered setup cost values.

The most important observations from Table 10 are:

- If setup cost goes down, the number of batches increases and the savings decrease;
- If setup cost goes up, the number of batches decreases and the savings increase;
- The plain and cyclic models show the same effect (albeit that the cyclic model is constrained to a maximum of 16 batches).

		Inventory cost -50%				Default settings				Inventory cost +50%			
Product	Category	*Plain model*		*Cyclic model*		*Plain model*		*Cyclic model*		*Plain model*		*Cyclic model*	
		# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings	# Batches	Savings
1	A	58	€ 13,744	16	€ 17,481	82	€ 16,671	16	€ 22,271	101	€ 20,048	16	€ 27,063
2	A	25	€ 1,213	16	€ 3,034	36	€ 1,329	16	€ 4,049	44	€ 1,769	16	€ 5,051
3	A	10	€ 602	11	€ 77	15	€ 777	16	€ 44	18	€ 1,172	16	€ 453
4	B	28	€ 3,488	15	€ 9,936	40	€ 4,469	15	€ 13,216	49	€ 6,243	15	€ 16,499
5	B	7	€ 6,687	7	€ 9,280	10	€ 5,769	10	€ 9,192	12	€ 5,249	12	€ 9,121
6	B	3	€ 910	4	€ 749	4	€ 894	6	€ 786	5	€ 995	7	€ 922
7	C	2	€ 524	2	€ 492	3	€ 440	3	€ 566	4	€ 347	4	€ 555
8	C	2	€ -139	2	€ 199	3	€ -424	3	€ 140	4	€ -601	4	€ 135
9	C	0	€ 296	1	€ 215	1	€ 542	1	€ 477	1	€ 809	1	€ 740

Table 11 - Model outputs for altered inventory cost values

The most important observations from Table 11 are:

- If inventory cost goes down, the number of batches decreases and the savings generally increase;
- If inventory cost goes up, the number of batches increases and the savings generally increase;
- The plain and cyclic models show the same effect (again, the cyclic model is constrained to 16 batches).

Setup and inventory cost adjustments have a more or less opposite effect on the optimal number of batches to be produced. This confirms our intuition, because the trade-off is between these two variables; if they would not oppose each other there would not be a trade-off in the first place.

The last C-category product should not be produced in case of setup cost increase or inventory cost decrease. This is due to the small annual production of this SKU, causing the change in parameters to have a relatively large impact. For the other SKUs, conclusions do not change when parameters are adjusted: the optimal number of batches and associated savings change, but the direction of the change is consistent.

6 – CONCLUSIONS & RECOMMENDATIONS

This research was built from a few key questions around the central theme of the project. This chapter provides an overview of main conclusions, implementation challenges, and corresponding recommendations. Section 6.1 addresses the conclusions to the questions as formulated in Chapter 1. Section 6.2 deals with practical implications of the implementation from an engineering as well as organizational point of view. Section 6.3 contains recommendations regarding batch sizing within the context of this research.

6.1 THE RESEARCH QUESTIONS REVISITED

6.1.1 RECAP

The main research question was defined as:

"Is it economically feasible to reduce inventory in the AC EMEA supply chain by producing in smaller batch sizes?"

In order to enable answering the main research question, four sub-questions have been formulated; all four have been covered in their corresponding chapters:

1) *What is the current situation regarding supply? (Chapter 2)*
2) *What does literature say about batch sizing and the economic feasibility of batch size reduction? (Chapter 3)*
3) *What is the desired situation regarding supply? (Chapter 4)*
4) *Can the discrepancy between current and desired be bridged by making smaller batch sizes?*
    i. *What is the influence of batch sizes on operating cost? (Chapter 4)*
    ii. *What is the influence of batch sizes on inventory cost? (Chapter 4)*
    iii. *Under what conditions is producing in smaller batch sizes economically feasible? (Chapter 5)*

6.1.2 WRAP-UP

Currently, there is a tendency towards producing relatively large batches. This has various causes, including the costing model discouraging production in smaller batches, the production facilities not being designed for smaller batch production, and a general tendency to keep things simple and avoid small batches.

As we have seen during this project, and as described in this thesis, it seems to be economically feasible to produce smaller batches in many cases, which leads to an inventory reduction within PPG AC warehouses. Literature generally supports this line of thought.

Producing in smaller batch sizes has many advantages. For most tested cases, these seem to outweigh the disadvantages. The full batch size optimization cycle is quite laborious, yet for every individual SKU a unique pattern should be determined. Even though for some cases the gain of altering the usual production schedule seems marginal, one should note that taking calculated decisions on batch sizes will always be an improvement.

However, the analysis has been mainly based on economical arguments thus far. Altering the production schedule drastically will most probably cause many practical issues. As stated, factories simply have not been designed for producing small batches. Nevertheless, this does not imply that the research therefore is impracticable. When more insights in the real effects of producing smaller batches have been gained, perhaps by means of a pilot, a turnaround in managerial decision making and industrial assets design can be realized. Gradually, the processes will facilitate the optimal production policies more adequately.

6.2 IMPLEMENTATION

6.2.1 Engineering Challenges

As introduced in the previous chapters, changing batch sizes will potentially trigger a few bottlenecks in production. The most aggravating change will clearly be the increase in setup times. Due to the nature of setups during the paint production process, complexity may rise more than proportionally. For not only will the idle time be higher for most lines; also, the more frequent switching between paints of different qualities and color types will cause an increase in required cleaning procedures.

We recommend looking into opportunities for setup time reduction, for these will most probably reduce the pressure on the scheduling constraints that are raised by the increase in setup frequency. There might be cheap and straightforward ways to reduce setups. At the filling lines for instance, the shoots in which the paint is released from the factory piping could be installed in pairs, so that one is operational while the other is being cleaned. It might also be possible to make some modules in the production and filling lines replaceable, which enables a quick change for a cleaned set.

One should bear in mind that the factories have not been designed for the modern, flexible production process and that there will be some quick wins by applying small adjustments to the process and facilities. Most importantly, a new batch sizing policy is discussed very well within the Industrial Assets teams, thus enabling them to evaluate the importance of setup time reduction in their tenders for contracts in new investment situations or even when designing new factories.

6.2.2 Organizational Issues

Making smaller batches is in some cases the exact opposite of human intuition. Of course, when looking form a factory point of view, this might only make life more difficult or more complex at the very least. People will always be tempted to pair up small batches, with the best of intentions. But, despite the good intentions, it is this kind of behavior that causes a huge deal of the inventory that is being held all over the warehouses. Thus, a very serious implementation challenge is to give people the opportunity to adapt to a new way of thinking and being efficient. The positive results of reducing inventory will not be directly visible to many factory employees.

By starting a pilot in reducing the few largest batch sizes, the effects will be as visible as possible, while the production process itself is altered relatively moderately. This will, amongst other things, enable employees to experience the increase in flexibility that the batch optimization will cause, without deteriorating the entire production system.

6.3 RECOMMENDATIONS

6.3.1 Aimed Approach

As we have seen in the analysis phase of this research, the larger part of production volume is in the larger batches of A-products. Recall that the extent of the batch size reduction as well as the relative saving per kilogram is relatively small for this class of products. Nevertheless, due to the huge volumes, the absolute savings in this category will be very significant. As seen in Chapter 5, the largest A-category batches already are produced in high frequency. Therefore, we recommend focusing on initially reducing the A-articles with relatively small production volume and the larger B-articles. It is of key importance to choose an aimed strategy to approach the pilot phase of batch size reduction.

Besides, it will always make sense to reduce the largest batch sizes first, especially when demand for that SKU is low. Consequently, the ratio between batch size and demand is a good indicator of successfulness of batch size reduction. Gradually adopting the way of production and the batch sizing process to the more optimal scenario will yield some large and some moderate saving over the entire production line. Combining these savings will amount to millions for the VFU factory.

One should bear in mind that many practical issues need to be dealt with. Nonetheless, we recommend starting to make optimal batches under the current capacity and labor restrictions and analyze where the bottlenecks pop up. A practical way to not flood the factories with setup time increases is to start connecting more filling batches to one production batch, for this will only increase complexity on the filling lines.

We also have seen that the current production costing model does not facilitate a change in batch sizes. This should be noted when assessing the successfulness of the pilot phase. Adjusting the tariff system would also be an option, yet this is very deeply intertwined with financial and production systems, so this will expectedly yield more problems than it solves.

6.3.2 Optimization in Practice

As we have seen, the optimization process can be quite comprehensive. Therefore, it may be useful to develop a more elaborate batch size optimization tool. Such a tool could be developed within the existing SAP systems. Ideally, such a model would continuously update optimal batch sizes and would be embedded in the planning processes, so that truly optimal decisions can be made.

However, testing the effects of batch size reduction in practice has priority over finding the full theoretical truth. Hence, we recommend developing a more practical calculation model, like the one used for this research. This enables Supply to identify the interesting groups of SKUs that have high potential for inventory reduction.

6.3.3 Opportunities

During the project, some additional opportunities have been identified that would also reduce inventory, yet put less pressure on the setup times and complexity of factories. The first and most obvious one is to reduce the number of unique product formulations while maintaining the product range. In other words, fill more SKUs from the same recipes. This is a very practical way to cope with the wide product ranges while maintaining simplicity in the factory environments.

A second opportunity that could drastically reduce inventory is to move the customer order uncoupling point downstream. This can for instance be realized by producing more paint types as a base paint and then tinting them in a dedicated made-to-order facility. This deals with the problem of having stock in every color over the full product range.

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APPENDICES

APPENDIX A - COMPANY HISTORY

A.1 PPG INDUSTRIES, INC – A DIVERSIFIED MULTINATIONAL

With its origins going back to 1883, PPG Industries has a rich history. The firm was founded as the Pittsburgh Plate Glass Co. by Capt. John B. Ford and John Pitcairn in Creighton, Pennsylvania. After more than a decade of rapid growth, the first chemical facility was opened in Barberton, Ohio in 1899. An interest in the Patton Paint Co. was acquired a year later. The combination of glass and paint turned out to be lucrative during the first decades of the 20th century, with a large expansion in construction and the automotive industry.

PPG entered the optical products business in the early forties and in 1952 the fiber glass market was added to the business. In 1968, the name PPG Industries was adopted, due to the increasingly global presence of the company. This worldwide growth was successfully accelerated over the next decades.

In 2008, PPG acquired the SigmaKalon group, thereby making it the second-largest global coatings company and greatly expanding its presence in Europe, Asia, and Africa. Most of the Asian presence of SigmaKalon was integrated with PPG's existing business in those regions, whereas the European, African, and Middle Eastern parts have remained sovereign as PPG AC EMEA.

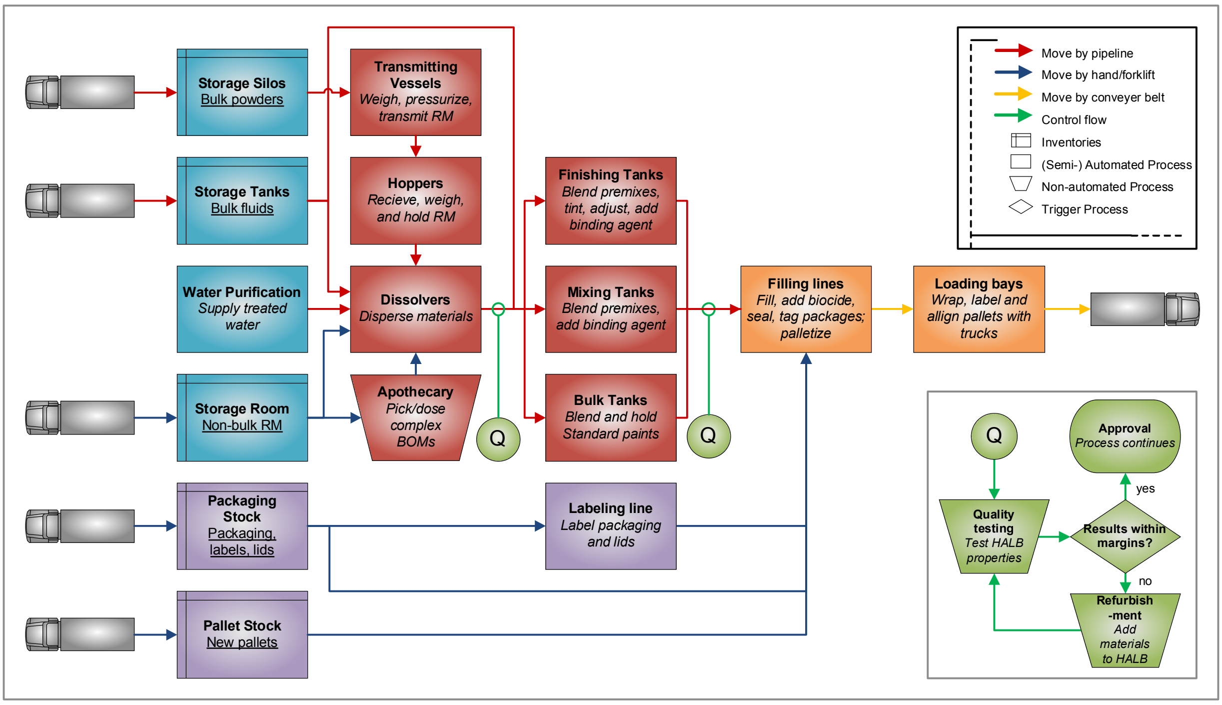
A.2 PPG ARCHITECTURAL COATINGS EMEA – A DUTCH PAINT CONGLOMERATE

PPG AC EMEA has gone through quite a lot of stages to become what it is today. Back in the 18th century, the first foundations were created by three individuals: Pieter Schoen started grinding pigments in a windmill in a region known as the Zaanstreek, the artist Louis Varrossieau opened up a small varnish making facility behind his house in the Dutch town of Alphen aan de Rijn, and Vettewinkel & Co engaged in selling some of their own paint to fellow carpenters in Amsterdam. During the next centuries, all three companies remained to exist, and in the meantime the paint business grew tremendously.

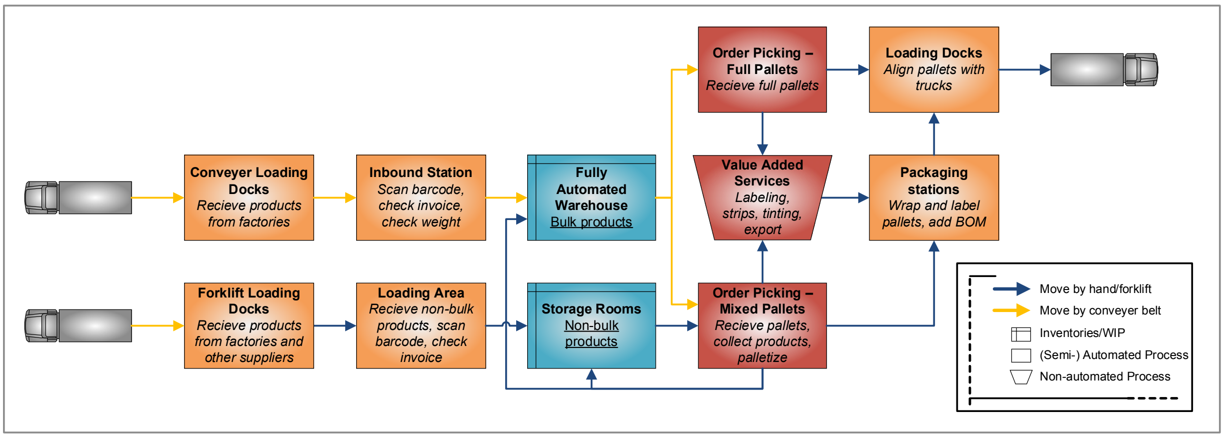
During the late sixties of the 20th century, there were many paint suppliers on the Dutch and international markets, resulting in a tendency towards mergers and acquisitions to obtain steady market shares. In 1972, all three 18th century companies mentioned were bought by Petrofina, a Belgian oil company, and merged into Sigma Coatings, with its headquarters in Uithoorn.

In the year 1999, Petrofina merged with the oil company Total, whereby Sigma Coatings merged with Kalon Group to form the SigmaKalon Group. One year later, oil company Elf was also merged into the conglomerate, now going by the name of TotalFinaElf. SigmaKalon was bought by investment firm Bain Capital in 2003 and was sold again in 2008 to PPG Industries, after a few years of organizational reform. From that moment on, SigmaKalon is known as PPG AC EMEA: PPG's largest acquisition ever.

APPENDIX B – TYPICAL PAINT PRODUCTION PROCESS OVERVIEW



APPENDIX C – TYPICAL PAINT WAREHOUSING PROCESS OVERVIEW



APPENDIX D – LITERATURE OVERVIEW COST OF CARRYING

Author	Publication	Estimate of Carrying Costs as a % of Inventory Value
L.P. Alford & John R. Bangs (eds.)	*Production Handbook*, (New York: Ronald Press, 1955) p. 397.	25%
George W. Aljian	*Purchasing Handbook*, (New, York: McGraw-Hill, 1958), pp. 9-29.	12-34%
Dean S. Ammer	*Materials Management*, (Homewood, Ill.: Richard D. Irwin, 1962), p. 137.	20-25%
Donald J. Bowersox, David J. Closs and Omar K. Helferich	*Logistics Management*, 3rd ed., (New York: Macmillan, 1986), pp. 189-97.	20%*
Joseph L. Cavinato	*Purchasing and Materials Management*, (St. Paul, MN.: West Publishing, 1984), p. 284.	25%
J.J. Coyle and E. J. Bardi	*The Management of Business Logistics*, 3rd ed. (St. Paul, MN.: West Publishing, 1984), p. 144.	25-30%
Gordon T. Crook	"Inventory Management Takes Teamwork," *Purchasing*, March 26 1962, p. 70.	25%
Thomas W. Hall	"Inventory Carrying Costs: A Case Study," *Management Accounting*, January 1974, pp. 37-39	20.4%
J. L. Heskett, N.A. Glaskowsky, Jr., and R. M. Ivie	*Business Logistics*, 2nd ed. (New York: Ronald Press, 1973), p. 20.	28.7%
James C. Johnson and Donald F. Wood	*Contemporary Physical Distribution and Logistics*, 3rd ed. (Tulsa, OK.: PenWell Publishing, 1986), p. 253.	25%
John F. Magee	"The Logistics of Distribution," *Harvard Business Review*, July-August 1960, p. 99.	20-35%
Benjamin Melnitsky	*Management of Industrial Inventory* (Conover-Mast Publication, 1951), p. 11.	25%
Thomson M. Whitlin	The Theory of Inventory Management, (Princeton, NJ.: Princeton University Press, 1957), p. 220.	25%

* Not specified, although 20 percent was used in examples.

Source: REM Associates of Princeton, Inc.

APPENDIX E – COSTING MODEL

<<Tables classified>>

APPENDIX F – VFU-PRODUCED BRANDS AND THEIR PRODUCTION CHARACTERISTICS

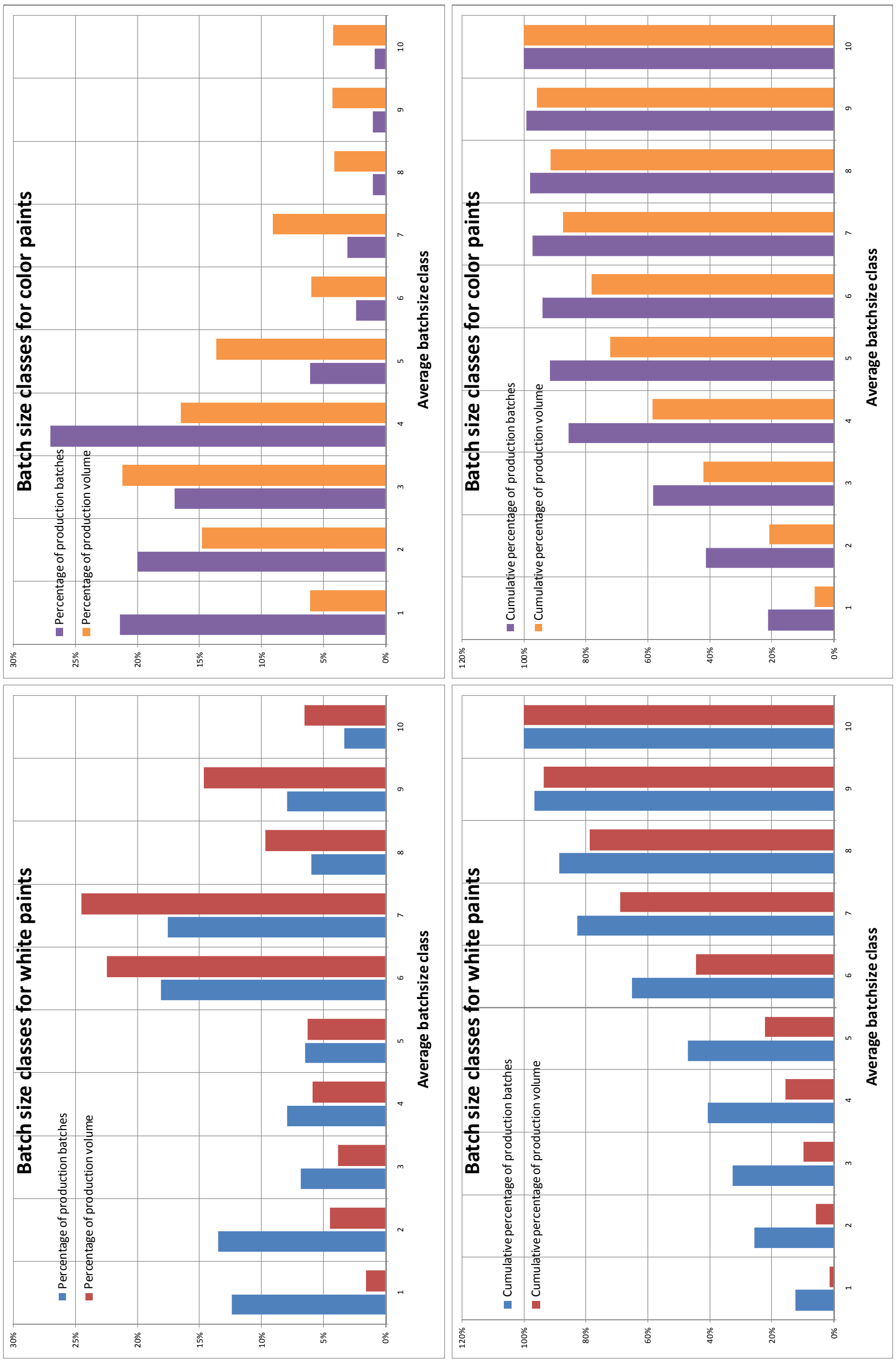
<<Table classified>>

The number of unique SKUs shows how many different products have been produced under the corresponding brand. Note that due to the overlapping processes in production and filling batches between different brands, the number of HALB orders per brand and thereby also the average filling batch size have been estimated.

APPENDIX H - TOTAL COST VERSUS AVERAGE BATCH SIZE PATTERNS

<<Graph classified>>

APPENDIX G – BATCH SIZE CLASSES AND VOLUMES



The average batch sizes of all SKUs produced in the VFU in 2010 are divided into ten same-length intervals. For each of the intervals, the diagrams show the total production volume and total number of batches in that class. The two diagrams on the left show the normal and cumulative histograms of white paints; those on the right show the color paint histograms.