# Master-Thesis

Concept development for designing an optimal production planning and control

TECHNISCHE UNIVERSITÄT DARMSTADT

PTW TU DARMSTADT

Author: Juan Carlos Camborda
Matr. Nr.: 2630517
Tutor: M.Sc. Eva Schaupp
Submitted: Darmstadt, 16.03.2016

**- Offizielle Aufgabenstellung einfügen -**

Die Version für die Bibliothek muss die unterschriebene Originalversion der Aufgabenstellung enthalten. Alle anderen Versionen enthalten Kopien der unterschriebenen Originalversion.

## Declaration of honor

1. Hiermit erkläre ich, die vorliegende Masterarbeit ohne die Hilfe Dritter, nur mit den angegebenen Quellen und Hilfsmitteln angefertigt zu haben. Alle Stellen, die den Quellen entnommen wurden, sind als solche kenntlich gemacht worden. Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

____________________________ ____________________________

(Ort, Datum) (Unterschrift)

2. Folgende Einverständniserklärung ist unabhängig vom Prüfungsverfahren zur Diplomprüfung (ein Exemplar verbleibt bei den Prüfungsakten) und ohne Einfluss auf die Bewertung der Masterarbeit. Dies gilt insbesondere für den Fall, dass Sie mit der Aufnahme in die Bibliothek nicht einverstanden sind [siehe Ziffer 2b].

   a. Mir ist bekannt, dass ein Exemplar der Masterarbeit Bestandteil der Prüfungsakte wird und bei der TU Darmstadt verbleibt [§19 Abs. 7 Diplomprüfungsordnung / Allgemeiner Teil (DPO/AT) vom 15. Juli 1991 (Amtsblatt 1992, S.23) in der Fassung der zweiten Änderung vom 7. Februar 1994 (Amtsblatt S. 441)].

   b. Ich bin damit einverstanden / ~~nicht einverstanden~~ (bitte nicht entsprechendes streichen), dass die Masterarbeit in den Bibliotheksbestand der TU Darmstadt aufgenommen wird und öffentlich zugänglich gemacht wird.

____________________________ ____________________________

(Ort, Datum) (Unterschrift)

3. Die TU Darmstadt bittet Sie im Interesse eines freien Informationsaustausches, ihr Urheberrecht an der Arbeit zu wissenschaftlichen Zwecken nutzen zu dürfen. Sie können die Nutzung Ihres Urheberrechts durch die TU Darmstadt ohne Angabe von Gründen und ohne nachteilige Folgen für die Bewertung der Arbeit verweigern. Ich bin damit einverstanden / ~~nicht einverstanden~~ (bitte nicht entsprechendes streichen), dass die TU Darmstadt das Urheberrecht an meiner Masterarbeit zu wissenschaftlichen Zwecken nutzen kann.

____________________________ ____________________________

(Ort, Datum) (Unterschrift)

## Acknowledgements

Foremost, I would like to express my sincere gratitude to J.G and T.S for their immense leadership and for offering me the unique opportunity of writing this thesis in their team. Their guidance helped me throughout the realization of this work. I could not have imagined having better mentors for my Master Thesis.

My sincere thanks also goes to Professor Dr. Eberhard Abele and Eva Schaupp for giving me the opportunity to write my Master Thesis in the industry.

Finally, I can only show eternal gratitude to my family and my partner for the continuous support along all these 6 years and for their relentless faith in me. It would have been impossible without them.

---

*“Ante todo, quisiera expresar mi sincero agradecimiento a J.G y T.S por su inmenso liderazgo y por ofrecerme la oportunidad única de escribir esta tesis en su equipo. Su orientación me ha ayudado a lo largo de la realización de este trabajo. No podría haber imaginado tener mejores mentores de mi proyecto final de máster.*

*Mi más sincero agradecimiento también va al Profesor Dr. Eberhard Abele y a Eva Schaupp por darme la oportunidad de escribir mi proyecto final de máster en la industria.*

*Por último, sólo puedo mostrar agradecimiento eterno a mi familia y a mi pareja por el apoyo continuo a lo largo de estos 6 años y por su implacable fe en mí. Habría sido imposible sin ellos.”*

## Abstract

As opposed to the widespread use of lean in discrete manufacturing industries such as automobile, motorcycle or computers, Process Industries have historically lagged behind in the application of lean practices due to the rigid conditions of their manufacturing activities (e.g. inflexible equipment, long set-ups and expensive changeovers). However, even process industries present some degree of discretization as introduced by some authors [ABDU07, POOL11]. In addition to the discretization point of a process manufacturing environment, recent studies presented by several scholars [KING09, KING13, LYON13, PACK14] have highlighted the importance of analysing the manufacturing environment in detail in order to classify products and production resources for optimizing production planning and control processes.

This work takes a real example as a case-study to analyse the manufacturing environment in the Process Industry. Besides analysing the current manufacturing operations, this study will also assess the impact of the implementation of a new semi-continuous production process in the factory. Finally, it will suggest a lean production planning and control approach based on Josef Packowski's High-mix Rhythm Wheel [PACK14].

## Table of Contents

## List of figures

## List of tables

# Abbreviations

| | |
|---|---|
| AOQ | Average order quantity |
| APICS | American Production and Inventory Control Society |
| CT | Cycle time |
| BoM | Bill of material |
| CO | Changeover |
| CoV | Coefficient of variance |
| CRP | Capacity Requirement Planning |
| DRP | Distribution Requirement Planning |
| EPE | Every Product every cycle |
| ERP | Enterprise Resource Planning |
| IRL | Inventory replenishment level |
| JIT | Just-in-time |
| MPS | Master production scheduling |
| MRP | Material Requirements Planning |
| MTO | Make-to-order |
| MTS | Make-to-stock |
| OEE | Overall equipment efficiency |
| OOA | Order of addition |
| PPC | Production planning and control |
| QTY | Quantity |
| TR | Technical Requirements |
| SKU | Storage keeping unit |
| SMED | Single minute exchange of die |
| TPM | Total Productive Maintenance |
| TPS | Toyota Production System |
| VSM | Value stream map |
| WIP | Work in process |
| WO | Washout |

# 1 Introduction

*"A bad system will defeat a good person every time"*

W. Edwards Deming (1900-1993)

## 1.1 Motivation

Lean manufacturing principles derived from the Japanese manufacturing industry have been widely used in manufacturing companies over the past decades. Throughout the years they have adopted a variety of names until "lean" actually began to gain popularity. Companies following these practices have been so successful that the use of lean has spread across the entire supply chain. More recently, lean has been adopted in the improvement of business processes or across entire enterprises (product development, legal department, human resources, etc.). However, there still seem to be a very low adoption of lean practices in manufacturing operations of what is known as the process industries. Books are full of examples showing lean being applied to discrete manufacturing industries, such as automobiles or computers.

Many scholars seem to agree that while in discrete industries the lean practices can be easily generalized and applied across several industries with the same principles, this is not the case in process industries. Even within process industries, the applicability of certain lean practices cannot be generalized. Some authors speak of "lean tools needing little modification" and "lean tools needing a different approach". They highlight that a company should be analysed and only some lean practices will be applicable after adjusting them accordingly.

This work presents an excellent opportunity to look into the manufacturing operations of a process industry and develop a tailored lean approach.

## 1.2 Problem definition and objectives

The aim of the present work is to assess the impact of a new manufacturing process and develop a holistic solution that minimizes the operating costs along the supply chain by applying a lean methodology. To do so, the study will rely on a real example presented by a company in the Consumer-Goods industry.

Despite the fact that process industries lag behind in terms of lean adoption and its suitability is still under debate, this work will also follow literature guidelines to finally make a lean production planning and control proposal.

This new manufacturing process will cause a major shift in the material flow between storage, making and packing areas. The process will shift from a batch production to a semi-continuous production. This causes uncertainty regarding the impact of the new process on the plant's operations.

As of now, mixer vessels transform raw materials into intermediate product in a batch process, prior to the packaging process. At any particular moment there could be different compounds in production that will flow to several packing lines through a buffer storage system. However, in the near future, a single set of equipment will be responsible for the entire making production, funnelling all the material flow through a single machine in a continuous manner. This new process will only be able to produce just one compound at a time, thus putting pressure on flexibility.

In this study the new situation is properly analysed, providing understanding of the implications in terms of possible capacity constraints (i.e. bottle-necks), change-over losses and material flow through all the production interfaces. As a result, this work delivers a proposal to achieve minimal costs while maximizing flexibility and service by applying a lean approach.

## 1.3 Delimitation of the work

The lean philosophy is very widespread in the industry. However, in this work the focus will be on the applicability of lean practices in the process industries. In particular, the lean tools that will have more relevance are linked to the area of Production Planning and Control processes. The intention is to provide a solution that improves the current situation and deals with the changes of the new manufacturing process.

To conduct the required analysis of products and resources, the focus will be set on the interfaces of capacity, productivity, changeovers and material flow.

The core of the study will be the analysis of Making and Packaging departments.

## 1.4 Procedure and structure of the work

The work has been structured in 7 chapters. The main study comprises chapters 4,5 and 6.

Chapter 4 does a thorough analysis of the current state of the manufacturing plant in order to provide an understanding of the current operations. Chapter 5 changes its focus into the future state, measuring and understanding the impact of the new manufacturing process. Chapter 6 finally gathers information from the previous chapters and makes a proposal.

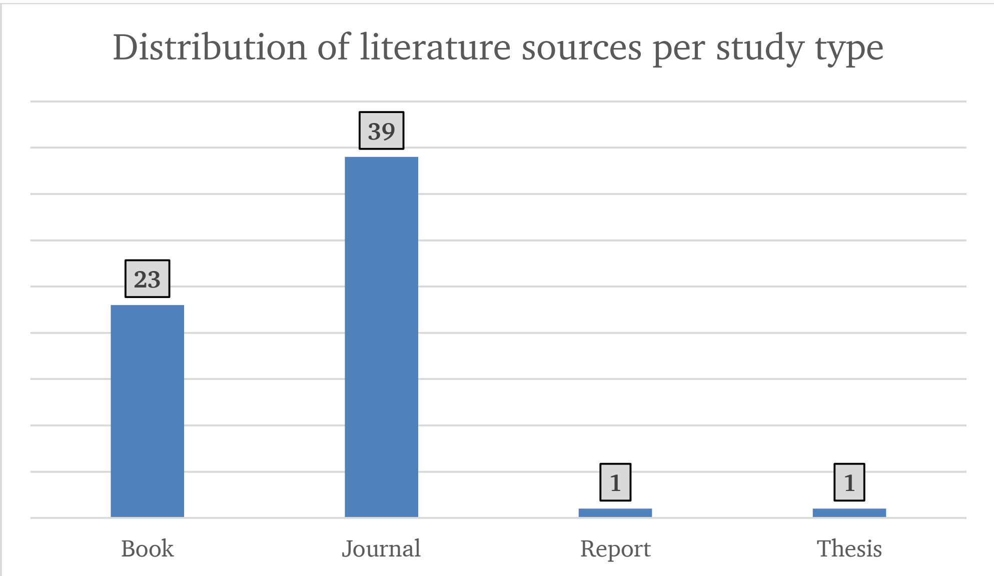



Figure 1: Distribution of literature sources per study type

# 2 State of the art

*"By seeking and blundering we learn"*

Johann Wolfgang von Goethe (1749-1832)

## 2.1 Classification and segmentation of products

**ABC Analysis**

The ABC Analysis is a very useful tool to classify products based on their value. The concept of value can take different forms depending on the objective of the classification [WERN07].

- **A-Goods:** They typically entail a very large share of the total value of items (around 70%) but only a few items (around 20%).
- **B-Goods:** The represent a moderate portion of the value (around 20%) but a larger number of items (around 30%)
- **C-**Goods: Finally, C-Goods have the lowest value (around 10%) and is comprised by a relative high share of the items (around 50%)

**XYZ Analysis**

According to [WERN07], the classification of X, Y or Z goods is made based on the demand variability and forecast accuracy:

- **X-Goods:** A very uniform (largely deterministic) consumption describes X-Goods. There are slight variations in demand and high sales forecast accuracy.
- **Y-Goods:** They are characterized by seasonal, trend-oriented or economic fluctuations. The prediction accuracy of the Y-Goods is moderate.
- **Z-Goods:** For Z-Goods non-uniform (stochastic) consumption is typical. The fluctuations in demand are high, and the prediction accuracy is low. For example, the seasonal business is subject to considerable fluctuations. The same may apply for the logistical control for a sales promotion campaign.

## 2.2 Overall Equipment Efficiency

Overall Equipment Efficiency (OEE) is an indicator used to understand the effectiveness of equipment and it is a function of Availability x Equipment Productivity x Process yield [FELD00]

OEE typically serves as a way to identify one of the six major losses that are found in a factory's equipment. The six losses are:

1. Breakdown
2. Changeover
3. Minor stops
4. Reduced speed
5. Rejections
6. Start-up losses

1 and 2 fall into the category of Availability (time losses), 3 and 4 are related with the Equipment Productivity or Performance Rate (speed losses) and 5 and 6 are linked to the Process yield (quality losses) [ERLA12].

## 2.3 Fundamentals of Lean

### 2.3.1 Lean Production

According to APICS [BLAC13], lean production is defined as:

*"A philosophy of production that emphasizes the minimization of amount of all the resources (including time) used in the various activities of the enterprise. It involves identifying and eliminating non-value-adding activities in design, production, supply chain management, and dealing with customers. Lean producers employ teams of multi-skilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety. It contains a set of principles and practices to reduce cost through the relentless removal of waste and through the simplification of all manufacturing and support processes."*

One way to provide clarity on the lean concept is to divide it in three different levels of abstraction as shown in Figure 2 [ARLB11].

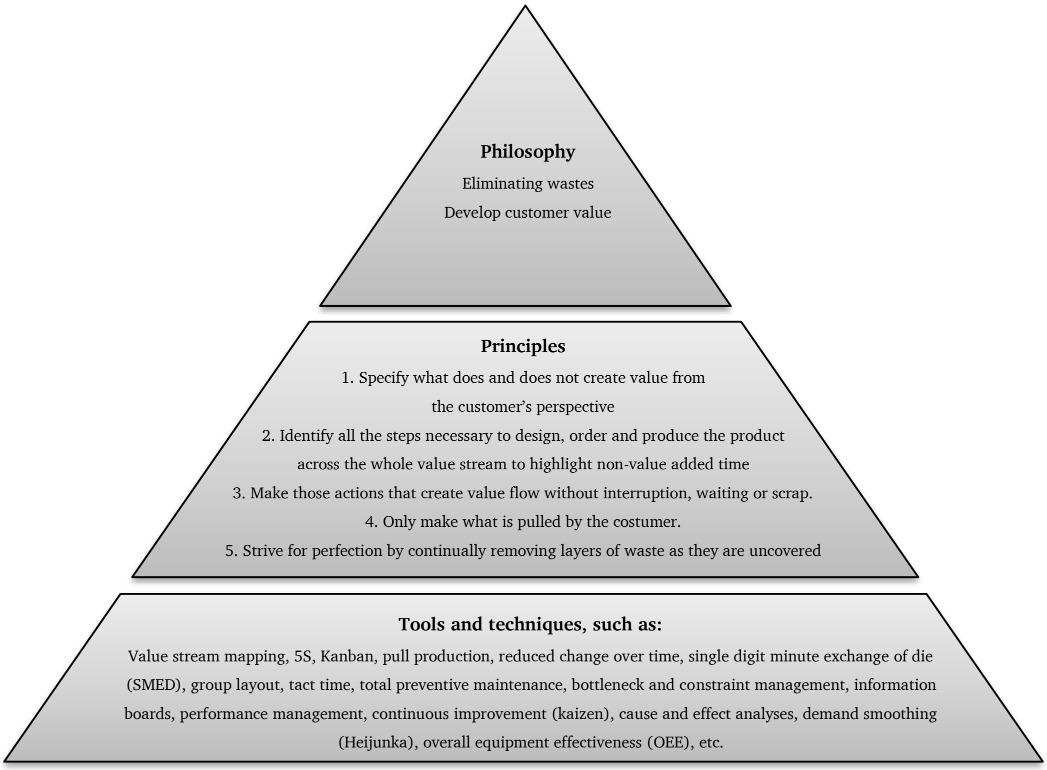



Figure 2: Three levels of lean perceptions [ARLB11]

### Background

The concept of lean was first coined after World War II when Japanese manufacturers had to face vast shortages of material, financial and human resources [WOMA90]. Kiichiro Toyoda, the president of Toyota Motor Company at that time admitted that American carmakers were surpassing by ten times the production of Japanese companies. These adverse conditions lead Japanese leaders such as Toyoda, Shigeo Shingo and Taiichi Ohno to develop a new manufacturing concept meant to be disciplined and process-oriented. This new approach is known today as the “Toyota Production System” or “Lean Manufacturing”. The system is focused on identifying and tracing the major sources of waste and then using tools such as Just-in-Time, reduced change-over time, production smoothing and others to eliminate it [ABDU07].

### The 8 Wastes

Within Toyota Production System (TPS), the wastes are the origin of efficiency losses [ŌHNO93]. As a consequence, the elimination of waste is one of the basic concepts of TPS [SUGI77]. Taiichi Ohno divides the work in two components, the actual necessary work while the remaining part is considered as waste [ŌHNO93]:

*"Current Capacity = Work + Waste"*

Brunner [BRUN14] suggests a more specific definition for waste and refers to it as the portion of non-value added activities within a production process. However, the wastes are not only found in production processes, but also in administrative areas. Gorecki and Pautsch [GORE13] therefore define wastes beyond production processes and state that waste is present on every activity.

In the literature a relative high agreement can be found regarding the type of wastes, although it can be said that there is evidence of "7+1" types of wastes, depending on the sources [BHAS15, CHIA15, SCOT11]. The 8 wastes are shortly summarized with examples in the following table:

| Waste category | Examples |
|---|---|
| 1. Overproduction | - Features, functionality and product performance that exceed customer requirements ("over-serve" the needs, "over-engineering", "performance over-supply")<br>- Completing elements that are not needed for some time |
| 2. Waiting | - Waiting time for information, test results<br>- Waiting times for decisions<br>- Waiting times for unavailable resources (human and physical)<br>- Waiting times for system response time |
| 3. Transportation | - Unnecessary exchanges of information<br>- Unnecessary exchanges of responsibility |
| 4. Overprocessing | - "Reinventing": wasting knowledge already developed in the past<br>- Complicated and redundant documentation, not designed according to the internal customer view<br>- Unnecessary or excessive reports or paperwork<br>- Receiving and discarding useless information<br>- Ex-post projects scheduling |
| 5. Inventory | - Too large "information batches" which slow the learning cycles and knowledge creation<br>- Retaining documents beyond what is required |

| | |
|---|---|
| 6. Unnecessary motion | - Searching for information<br>- Meetings not properly structured and focused<br>- Work characterized by constant interruptions and changes causing high "set-up" mental time |
| 7. Defects | - Modifications due to inadequate understanding of customer requirements<br>- Modifications due to service failures and missing or incomplete information |
| 8. Waste of knowledge (underutilized people) | - Communication barriers (physical, social) that prevent people to interact effectively in problem analysis and troubleshooting<br>- Lack of clarity and accordance on the vision of the product to develop<br>- Archiving project information without creating re-usable knowledge<br>- Limited authority and responsibility for basic tasks<br>- Lack of knowledge sharing |

Table 1: The 8 wastes (adapted from [CHIA15])

**Pull vs. Push principle**

In the previous section the different types of wastes were described. Among all of them it is said that overproduction is the worst, as it has a knock-on effect in multiplying all other wastes [BHAS15, WOMA03, TSIG12]. This type of waste is closely related to the push principle, where products are pushed throughout the supply chain without considering real consumption. In an effort of maximizing productivity and smooth production, this push principle typically results in overproduction of items that are not actually required by the customer at that time [BHAS15].

According to [BONN99], most of the production systems comprise elements of both push and pull. Based on literature research, it has been realized that there is considerably ambiguity in terms of a universal definition of pull, where JIT, Kanban and Pull are often used interchangeably, which can lead to confusion [HOPP04].

Ambiguity is such, that even Make-to-Order or Make-to-Stock, that usually are perceived as Pull-Environment and Push-Environment respectively, both could be considered either Pull or Push [HOPP04]. In fact, Ohno did not explicitly define pull [KING09] and thus, Hopp and Spearman conclude that the differentiating characteristic lies in the fact that pull explicitly limits system work-in-process (WIP). A pull system considers the actual system status thereby preventing the system from becoming overloaded or interrupted [HOPP04].

In the real world, it is hardly to categorize a supply chain as pure Pull or pure Push. In fact, it is usual to find hybrid systems that combine both principles. As a result, the Decoupling Point is a relevant parameter to define within hybrid supply chains [PYKE90, BONN99]. It is defined as the point in which there is a shift from Push to Pull. Upstream, the production is planned against stock based on forecasts (push) while downstream the production orders are triggered by actual consumption (pull). In other words, it is the meeting point for forecast-driven and order-driven activities [HOEK92, DONK01].

### 2.3.2 Methods and Tools

| **Lean Practices** | **Author [Source]** | | | | |
|---|---|---|---|---|---|
| | *Sohal and Egglestone [SOHA94]* | *Fullerton and McWatters [FULL01]* | *Cua et al. [CUA01]* | *Shah and Ward [SHAH03]* | *Rahman et al. [SHAM10]* |
| 5S | | | | * | |
| TPM | | * | * | * | * |
| Quality circles | * | | | | |
| Quality management program | * | * | * | * | |
| Pull production | * | | * | * | * |
| Kanban | * | * | | * | * |
| Kaizen | * | | | * | |
| Production levelling | | * | | * | |
| One-piece flow | | | | | * |
| Bottleneck removal | | | | | * |
| Cross functional teams | * | * | * | * | |
| New equipment | | | * | * | * |
| Poka-Yoke | | | | | * |
| Cellular manufacturing | * | * | | * | |
| Focused factory | | * | | * | |
| Flexible manufacturing system | * | | | | |
| Supplier integration and reduction | | | | | * |
| JIT Purchasing | | * | * | | |
| Quick changeover | | | | * | * |
| Setup reduction | | * | * | | * |
| Lot size reduction | | | | * | * |

| | | | | | |
|---|---|---|---|---|---|
| Competitive benchmarking | | | | * | |
| Process capability measurement | | | | * | |
| Safety improvement | | | | * | |
| Cycle time reduction | | | | * | * |
| Production strategies | | | * | * | |

Table 2: Lean practices mentioned in literature

In the next few paragraphs, a brief description of most common lean tools is presented [NAHM09, FELD00, MOND94, GORE13].

Cellular manufacturing:

Relies on the concept of organizing an entire process for a particular product or similar products together into a group or “cell” by grouping all the machines, equipment and operators in an easy arrangement that facilitate operations.

Just-in-Time:

JIT is very strongly related with the pull concept. In essence, just-in-time refers itself to a system in which a customer initiates a demand request which is then transmitted upstream the supply chain, thus “pulling” all requirements just in the time that they are required.

JIT Production requires a paradigm shift of mind-set for the majority of companies. Starting with a switch from Push to Pull, following with an orientation towards customer-driven demand (i.e. orders triggered by customers) or forcing production to be aligned with the consumer takt. The main objectives of JIT Production are to reduce lead time and minimize work-in-progress inventory. This is accomplished thanks to a continuous flow in a perfectly balanced utilization of the resources that guarantee an ideal takt, ensuring that the product is passed through the next processes in the right quantity at the right time.

This presents a particular challenge at companies that have assembly lines which are not part of a single chain and therefore an intermediate storage is required. The problem is aggravated by a high production mix due to the differences in the utilization and resource requirements that each type of product has. Quite often a pure JIT-Principle is not applicable and a puffer has to be managed by Kanban strategies.

Kanban:

Kanban systems serve to join unlinked processes through a signal-based control system that enables a JIT-Production. The system handles information and material flow between the involved processes and delivers information regarding the required materials and the required quantities that are needed at the next step through Kanban cards. This card control process forces the system to minimize WIP Inventory and holds it within limits. Figure 3 presents a numerical example of a Kanban control system with supermarket.

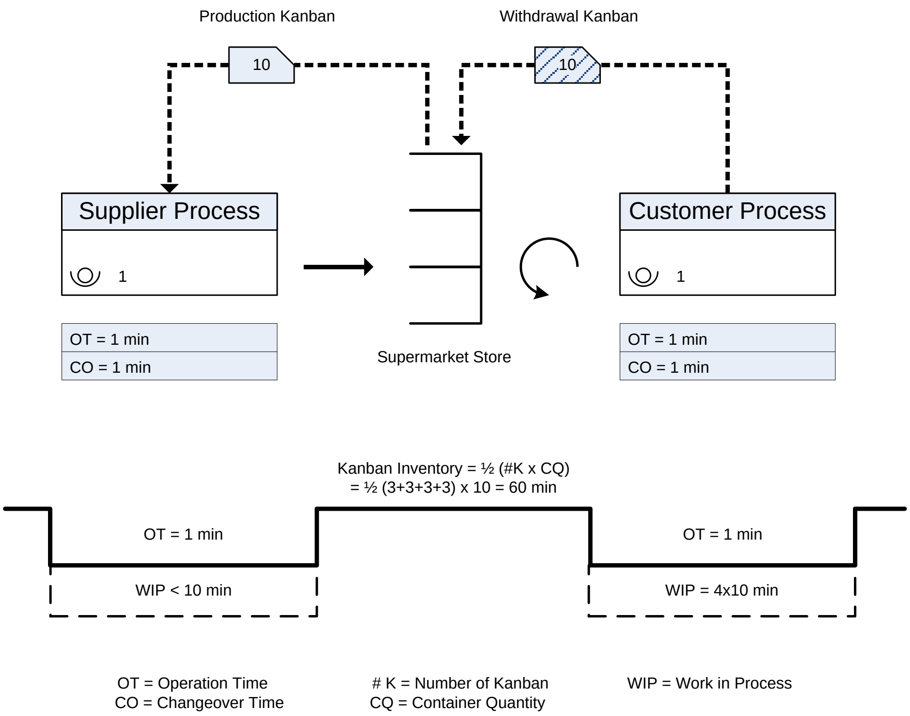



Figure 3: Kanban control with numerical example [ERLA12]

Total productive maintenance (TPM):

The main focus is to detect - instead of fix - possible breakdowns. This means that workers have to carry out regular maintenance in order to detect possible anomalies. Since the operators work permanently close to the machines, they take maintenance and monitoring responsibilities so that they can prevent and provide warning of any equipment malfunction.

Total quality management (TQM):

TQM consists on a management method of an organization that provides quality as a core aspect, always relying on the participation of all its members and aims at satisfying customer on long-term business success. Furthermore, this method pursues benefits for all the members of the organization and for society.

5S:

5S is an essential foundation block of lean and follows the principle of eliminating waste at work through discipline and standardization of processes or tasks. Standardization reduces wastes and prevents bad behaviours to end up producing unnecessary wastes again.

The 5S stand for: Seiri (Sort), Seiton (Set), Seiso (Shine), Seiketsu (Standardize), Shitsuke (Sustain)

### 2.3.3 Lean Production Planning and Control

Lean has been generally associated with production and manufacturing processes. However, the concept can be applied to every interface of an organization [BHAS15].

Bertrand et al. [BERT90] define production control as *"the coordination of supply and production activities in manufacturing systems to achieve a specific delivery flexibility and delivery reliability at minimum cost"*.

Therefore, lean concepts and tools for production planning and control are based on the principle of the alignment of production with demand [LYON13]. Since production scheduling is a critical manufacturing activity, the application of lean has emerged as an effective solution to bring major improvement to the organization. Scheduling activities deal with the distribution of available resources to tasks over a certain period of time [PINE12]. The complex and combinatorial nature of scheduling hinder and make it very intricate to apply any computational software to solve scheduling problems. Consequently, it is not always possible to find an optimal solution within a reasonable time period. To minimize this issue, many heuristic approaches have been developed. They provide near-optimal solutions in short time frames but in practice they often apply few dispatching rules that are simple to implement [PETR06].

In a lean environment, the peaks in production schedule need to be smoothed out in order to maximize capacity utilization. A smooth production would run all operations at a constant level. If the production was not levelled, then it would be extremely difficult to deal with uncertain and volatile demand fluctuations and the flow of raw materials or finished goods within the supply chain could be disrupted [SALM07, SCHU00].

The root lean tool for all other production planning tools that have evolved is Heijunka. Heijunka, also known as Production Levelling, is usually a way to manage Kanban cards through a “Heijunka Box” which is visually available at the shop floor. It allows a high level of schedule visibility that enables a constant production pace. Heijunka assumes that changeover times are not relevant to consider [POWE10, BECK08].

Nonetheless, Heijunka’s applicability is limited to predictable demand. In reality, when demand presents instability and uncertainty, Heijunka is not suitable [TSIG12]. Furthermore, Heijunka is more used in discrete, repetitive, assembly-type production with relative low variety of highly standardized products. Besides increased difficulty with higher product variety, time-consuming changeovers are also not appropriate for Heijunka [POWE10].

It is important to mention the environment in which lean planning tools have to be applied. Particularly, it is necessary to understand the working process and limitations of “Material Requirement Planning” (MRP)

**Material Requirements Planning**

MRP I is a system used for material requirements planning. The production quantities are already given by the system. However, the system’s available capacity is not considered. Over time, MRP I systems were complemented with CRP (Capacity Requirement Planning), MPS (Master Production Scheduling) and DRP (Distribution Requirement Planning). Later, MRP I turned into MRP II (Manufacturing Resource Planning). This tool checks the available capacity and calculates the material requirements independently. Quite often, this leads to inconsistences due to short capacity.

The structure of MRP and ERP are very similar. They both are organized in Bill of Materials (BoM) that contain the several layers of the materials. The systems are integrated in SAP. The main challenges of these systems in the context of Process Industries, is that they manage all the information at a finish product level. Managing intermediate products and planning according to them is very difficult to achieve and requires lots of efforts [WERN07].

## 2.4 Lean methods in Process Industries

Section 2.5 has provided an overview of the current state of lean in the industry and what the most widespread tools are.

The intention of section 2.6 is to study the applicability of the above mentioned lean concepts in process industries while highlighting the lack of extensive research available regarding to this field [SCHR94]. In fact, Panwar et al. recently emphasized that very little research has been conducted about lean manufacturing in process industries, as shown in Table 3 [PANW15]. It is interesting to note that this situation is still not showing any sign of change in recent years [BELV05, POOL11].

| Publication/Journal | Total number of papers related to lean manufacturing published since 1991 | Number of papers in context to process industries | % of papers related to process industries |
|---|---|---|---|
| International Journal of Operations and Production Management | 399 | 10 | 2,5 |
| International Journal of Production Economics | 489 | 6 | 1,2 |
| Supply Chain Management: An International Journal | 166 | 6 | 3,6 |
| Journal of Manufacturing Technology Management | 164 | 3 | 1,8 |
| International Journal of Production Research | 413 | 3 | 0,1 |
| Journal of Operations Management | 85 | 2 | 2,3 |
| Production Planning and Control | 42 | 3 | 7,1 |

Table 3: Distribution of research papers across journals [PANW15]

The next paragraphs present a thorough literature research that will help to clarify the specific challenges that process industries face, as well as the applicability of lean practices in this industry along with possible differences within the different types of process industries.

### 2.4.1 Is lean useful for the Process Industry?

At the philosophical level, lean has been useful for all types of industries regardless of their processes and products [SHAH03, WOMA03]. Historically, discrete manufacturing industries such as automobile and electronics have successfully applied lean methods. However, for other types of industries, for instance process industries, the suitability of lean is still under debate. Process industries present characteristics that significantly differ from discrete industries [LYON13]. Process industries and discrete industries are therefore not comparable due to fundamental differences [CRAM01]. Disagreement about researchers about certain lean methods in process industries is evident. Some authors believe in the applicability of lean practices such as Kanban and JIT production in process industries [JONS06] whereas other authors argue that these practices are not suitable for process industries [BONA06, ABDU07]. Authors such as Fransoo and Rutten show that the applicability of lean is also different within process industries. They introduce the importance of differentiating between continuous and batch process industries, as they present different characteristics in terms of yield, routing, equipment flexibility, level of WIP or product complexity [FRAN94]. Continuous and batch process industries require different production control strategies depending on their characteristics. Nonetheless there is little documentation in the literature that suggests which lean methods are valid for continuous process industries and which are applicable in batch process industries.

Kemppainen et al. suggest that the root cause for the failure of many lean practices in process industries is explained by a “misfit” between capital-intensive equipment and expensive product changes [KEMP08]. The equipment usually consists of compressors, pumps, evaporators or heat exchangers. In order to keep them running all the time without breakdowns Shah and Ward suggest applying TPM [SHAH03]. Implementation of lean practices in the textile industries show for instance that lean tools such as 5S, Kaizen, value stream mapping and visual control are widely used.

Nevertheless, some papers that studied the use of lean tools in process industries suggest that cellular manufacturing is not possible to implement in process industries [ABDU07, HODG11, JIME12]. Furthermore, many scholars conclude that setup reduction, visual factory and production levelling also have limited applicability [ABDU07, SHAH03, BONA06, HODG11]. Besides methods related with the elimination of wastes, there is also little evidence in the literature regarding involvement of suppliers or strategic purchasing [LYON13].

Literature explains that lean practices are applicable in process industries only when non-discrete products become discrete [MUKH05]. This conclusion necessarily implies that lean is almost inapplicable in continuous process industries where products do not become discrete at all, as in the petroleum industry. However, further research is required in order to confirm this assumption, as some researchers have provided empirical evidence with contradictory results [MAHA07].

Interestingly, some authors mention that the implementation of lean requires an adaptation of its methods according to the process, market and supply chain characteristics. Hence, some lean practices might not be applicable, some might be applicable and others might need an adaptation to fit the particularities of process industries [MELT05, RADN06].

In conclusion, there is still relative little research on the applicability of lean practices in process industries [DENN00, CRAM01]. Despite extensive analysis and validation of models, most of them remain founded in discrete manufacturing and thus there is limited agreement as to their applicability in the process industries. A few researchers have found that the magnitude of performance improvement through adoption of lean practices is much bigger in process industries than in other industries [TAJ11]. Its adoption in process industries not only offers operational advantages [SIMO05, POOL11] but also strategic advantages [PANW15].

### 2.4.2 Industry-specific challenges

The APICS dictionary [BLAC13] define process manufacturing as:

*“Production that adds value to materials by mixing, separating, forming or chemical reactions”*

As mentioned before, whilst all process industries present similar characteristics that differ from discrete manufacturing industries, it is important to further classify process industries:

- Batch process industry, defined by APICS as: *“a manufacturing technique in which parts are accumulated and processed together in a lot”*
- Continuous process industry, defined by APICS as: *“lotless production in which products flow continuously rather than being divided”*

This type of industries produce non-discrete materials, for example, liquids, pulps, gases, powders and slurries which cannot be storage without containerization [DENN00]. In the same study, authors note that process industries are considerably more complex than previous research suggests. They extend the APICS classification of process industries and present a 3-group approach, including the so called "hybrid" process industry, also known as "semi-process" industry. The 3 groups are sub-divided into more specific sub-groups depending on the level of intermittence/continuity of the products. Table 4 summarizes the different groups and includes examples of products associated with each group.

| **Group** | **Sub-group** | **Example products** |
|---|---|---|
| Intermittent | Process job shop | Specialty organic chemicals |
| | Custom blending | Specialty industrial cleaning chemicals, container coatings and feed additives |
| | Fast batch | Finishes, paints, pigments, inks, varnishes, ice cream, meats and baked goods |
| Hybrid | Custom hybrid | Flexible packaging |
| | Stock hybrid | Plastics, extruded packaging and tablets |
| Continuous | Multistage continuous | Beer |
| | Rigid continuous | Resins, mouthwashes, ointments, yeasts and beverages |

Table 4: Process industry classification according to product flow [DENN00]

Hybrid process industries consist of products that become discrete in some stage of the production process. This stage is called the discretization point, first introduced by Abdulmalek et al. [ABDU06] and later used by Pool et al. [POOL11]. Depending on how far in the process these products are discretized, it is possible to classify the industry in early, middle or late. This classification is represented in Figure 4.

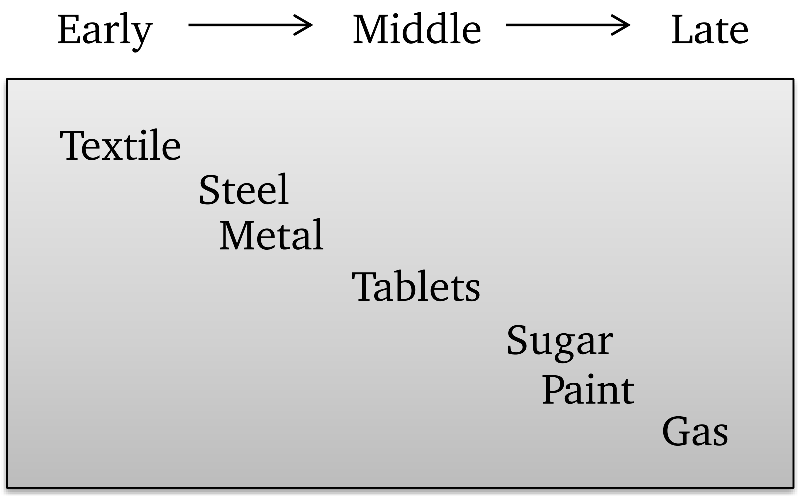



Figure 4: Classification of Process Industries based on discretization stage [ABDU06]

Process industries tend to have expensive equipment, are highly specialized and have a high degree of automation. Therefore, primary concern is to minimize operating costs and to get high return on assets [ASHA96]. It has been proved that process industries commonly operate with high levels of inventories along the entire supply chain, have many non-value added operations and achieve relatively low material efficiencies [SHAH05]. Despite the mentioned inefficiencies, some authors have found that process industries generally stay behind discrete industries as to the application of world-class manufacturing methods [GUNA98].

For instance, one of the reasons why "stopping the line" is not perceived as a valid lean tool for process industries [OLIV08] is the fact that a stop causes high time and material losses due to, for example, the need of processing at a particular temperature in order to assure the right product quality.

Long set-ups and changeover times are another source of lean incompatibility. They force long batch runs in order to maximize utilization so that intractable production costs can be avoided [POWE10]. An environment like this challenges the application of lean tools such as production levelling or pull production.

Furthermore, desired properties in products within process industries require strict material continuity and flow time. This causes a very difficult production scheduling [PACC04].

| Relationship with market | Process industries | Discrete industries | The Company |
|---|---|---|---|
| Product type | Commodity | Custom | Commodity |
| Product assortment | Narrow | Broad | Broad |
| Demand per product | High | Low | Variable |
| Cost per product | Low | High | Low |
| Order winners | Price | Speed of delivery | Price |
| | Delivery guarantee | Product features | Delivery guarantee |
| Transporting costs | High | Low | Medium |
| New products | Few | Many | Many |
| ***The product process*** | | | |
| Routings | Fixed | Variable | Fixed |
| Layout | By product | By function | By function |
| Flexibility | Low | High | Low |
| Production equipment | Specialized | Universal | Specialized |
| Labor intensity | Low | High | Low |
| Capital intensity | High | Low | High |
| Changeover times | High | Low | High |
| Work in process | Low | High | Limited |
| Volumes | High | Low | High |
| ***Quality*** | | | |
| Environmental demands | High | Low | High |
| Danger | Sometimes | Hardly | Sometimes |
| Quality measurement | Sometimes long | Short | Sometimes long |
| ***Planning and control*** | | | |
| Production | To stock | To order | To forecast |
| Long term planning | Capacity | Product design | Capacity |
| Short term planning | Utilization capacity | Utilization personnel | Utilization capacity |
| Starting point planning | Availability capacity | Availability material | Availability capacity |
| Material Flow | Divergent + convergent | Convergent | Divergent |
| Yield variability | Sometimes high | Mostly low | Medium |
| Explosion' via | Recipes | Bill of materials | Recipes |
| By and Co products | Sometimes | Not | Not |
| Lot tracing | Mostly necessary | Mostly not necessary | Mostly necessary |
| ***Additional characteristics*** | | | |
| Material variability | Yes | Low | Yes |
| Material availability | Variable | Stable | Variable |
| BOM/recipe | Sometimes variable | Stable | Sometimes variable |
| Quality variability | Yes | Reasonably stable | Yes |
| Process variability | Yes | Reasonably stable | Yes |
| Material cost | Low | High | Low |
| Changeover waste | Depends on product | Not | Depends on product |

Table 5: Comparison between process industries, discrete industries and the company studied (adapted from [ABDU06, CRAM01, FRAN94, SOMA04])

Table 5 provides interesting information, as it highlights the inadequacy of generalizing and comparing process industries with discrete industries while, at the same time, proves that process industries cannot be classified under the same group of characteristics. Besides further classification of process industries as the one proposed by Dennis and Meredith in [DENN00] or the one proposed by Abdulmalek et al. in [ABDU06], there is reasonable evidence to conclude that each company needs to be carefully and individually studied.

**Differences between Batch and Continuous Process Industries**

Batch sizes represent a serious constraint in batch process industries as they are limited by the fixed capacity of processing equipment. This limited flexibility hinders the implementation of JIT manufacturing strategies that require smaller batches because of the excess of waste that it would cause. To circumvent this obstacle, some companies expand their facilities in order to have mixing vessels of different batch sizes. However, this is not an option for many companies as process industries usually suffer from limited space for such expansions [PANW15]. Moreover, reducing the size of a batch below the equipment's capacity results in a throughput reduction and an increase in the cost of resources [AHMA05]. In terms of flexibility, literature shows that continuous process industries are the least flexible but they usually have single routing and simpler scheduling [BLOM98].

Despite the overall long change-over times that characterize process industries, batch process industries tend to have shorter change-over times that their counterpart. Consequently, batch process industries have shorter production runs. However, this also results in a higher WIP. Another consequence of batch production is the fact that the chemistry output is variable [FRAN94], in contrast with continuous processes where output chemistry is consistent [PART07]. Crama et al. report in [CRAM01] that batch process industries are characterized by a higher sequence of transformation processes than continuous process industries.

**Production Planning and Control challenges in Process Industries**

Traditional ways of measuring Key Performance Indicators in process industries are mostly related to capacity utilization, output and quality control. However, lean KPI's are not in the scope of the majority of companies in the process industry. Key parameters such as level of wastes, employees' suggestions, inventory levels or backorders are not considered when measuring performance [PANW15]. This presents an additional challenge to the organizations, as they lose sight of relevant parameters that play a significant role in decision making. In his study, Panwar et al. identify a potential area of research that would allow to measure analytically a company's leanness based on key characteristics.

As previously mentioned, MRP and ERP systems are not best suited for many process industries, which also hinders the application of Lean PPC practices in the industry.

### 2.4.3 Lean PPC tools used in Process Industries

The most extended lean practices in Process Industries are the Cyclic Planning Methodologies [BICH09].

Table 6 shows a summary of the different methodologies that can be found nowadays.

| | Heijunka | EPE | Product Wheel | Rhythm Wheel | | |
|---|---|---|---|---|---|---|
| | | | | Classic RW | Breathing RW | High-mix RW |
| **Product segmentation** | Product volume | Product volume<br>Demand variability | Product variability<br>Product demand<br>MTO/MTS | Product variability<br>Product volume<br>ABC/XYZ classification | | |
| **Production mix** | Fixed mix-model scheduling | Variables | Fixed mix | Fixed | Fixed | Different products each cycle |
| **Replenishment** | None (MTO)<br>Stock (MTS)<br>Kanban | Finished goods inventory (MTS) | None (MTO)<br>Stock (MTS)<br>Fixed interval<br>Fixed quantity | Variable quantity (IRL)<br>Fixed quantity (Buffer Mgt.)<br>None (MTO) | | |
| **Production sequence** | To even out peaks and troughs in the quantities produced<br>Negligible changeover times | Setup reduction<br>Changeover times and batch reduction | Changeover difficulty | Best changeover sequence<br>High utilization on the bottleneck operation | | |
| **Cycle time** | Fixed | Fixed | Fixed | Fixed | Variable | Variable |
| **Production quantities** | Fixed<br>Quantities equal to demand | Variables | Fixed | Fixed | Variable | Variable |

Table 6: Lean cyclic planning methodologies [FERN15]

The Product wheel [KING13] and the Rhythm Wheel [PACK14] are very similar and they are both founded on the same principles.

They suggest a series of steps in order to define the most suitable lean strategy to adopt depending on the company's particular situation.

Among these steps, it is possible to find the following analyses:

- Current State Visual Stream Map
- Bottleneck identification
- Product analysis (volume, variability)
- Determination of optimum sequence (based on changeover losses)

In the following chapters, the analyses will be oriented to gather all the information possible from each of the aforementioned 4 aspects. Based on the nature of the production processes in the plant, the study will be mainly targeted to apply an adapted version of the High-mix Rhythm Wheel suggested by Josef Packowski.

# 3 The company and the context of the work

*"Everything can be improved"*
Clarence W. Barron (1855-1928)

This chapter briefly introduces the characteristics of the company that will be used in the present work as a case-study of the applicability of Lean PPC methods in process industries.

The reader will quickly notice that the complexity of the company under consideration is extremely high. On top of the inherent complexity of the company's portfolio and its large supply chain, the introduction of a new manufacturing process will change the entire operations of the plant, especially affecting the material flow.

## 3.1 The company

The production of the goods in this plant serves not only the European markets but also other markets on the outside. The European region is originating increased complexity due to the large number of different languages. As a consequence, even same products need to be modified to suit local languages, increasing production complexity. Even worse is the situation with markets beyond Europe where legislations differ significantly. Furthermore, products are sold under different brands depending on the market. As a result, the factory is forced to manufacture different Stock Keeping Units (SKU's) for every specific market even if the content of the tubes is identical.

During the last decades, expansion in new markets and fierce competition in existing markets has led to an uncontrolled increase in the number of product variants that the plant has to deliver. Ultimately, such an extreme SKU complexity is causing a dramatic effect both on finished goods inventory levels and production costs. In addition, sustained growth via increasing sales has become a very hard task to achieve under current macroeconomic conditions and is putting tremendous pressure on cost-cutting so that companies can keep growing their profitability.

## 3.2 The manufacturing plant

The production is structured in the following two departments:

- Making
- Packing

Regarding the plant's layout, it is worthy to highlight that the layout is not fully optimized to promote smooth material flow within the plant, as the plant used to produce different products in the past. Space issues forced an inefficient layout and this has been causing losses in the form of unnecessary transportation.

Inbound shipments are handled through the north dock and the south dock. They have a limited storage capacity that is used to supply a few raw materials to some departments and conceived only for short-term storage. A high-rise warehouse stores raw materials, intermediates as well as finished goods. The high-rise Warehouse is seen as a potential source for wastes due to low turnover of some materials which occasionally makes the warehouse reach its capacity limit.

In the following paragraphs a brief overview of each department will be given. A more detailed analysis of them will be conducted in Chapter 4.

Essentially, Making can be seen as a "supplier" of the Packing department. In later chapters the importance of the synchronization between Making and Packing will be highlighted.

**Making**

Making accomplishes the core transformation of the product in order to turn a mix of chemicals into the final product. There are a total of 17 mixer vessels with similar capabilities that run at very similar rates. There just a few specific capabilities available for a reduced number of mixers. These capabilities are meant to produce some special formulas.

The raw materials are fed into the mixer in different ways:

- Solid raw materials are previously introduced in a trolley. The trolley is loaded in an independent equipment called the Handling Material System
- Main liquid raw materials are directly fed into the mixer through a weighing scale. The liquids are stored in big Silos

- Minor solids and liquids such as colouring agents are handled manually and added by the operators into the mixer vessels

Once the mix is finished, the batches are stored in big containers of the size of a batch.

**Packing**

Packing hold the last step of the production process: packaging. The production runs automatically. The operators have to focus on providing the machine with the required materials of packages, foils, etc.

There are 12 packaging lines:

- 8 low speed lines running at 250 tubes/min
- 4 high speed lines running at 530 tubes/min

Some of the lines are specialized in certain types of packaging.

## 3.3 Product portfolio

The plant manufactures up to 1000 different finished products. They are made of up to 40 different formulations and can contain 10 different flavours. Among the portfolio are several local and international brands. In terms of product characteristics, the portfolio can be classified in five different groups:

1. Family A
2. Family B
3. Family C
4. Family D
5. Family E

Each product family can be classified in terms of packaging complexity, manufacturing costs and price point.

**Project Mystery**

Project Mystery plays a pivotal role in this study. In section 3.2 the making department has been briefly described but will be heavily affected by this project. The objective is to drive savings across all cost components. To do so, it will dramatically change the making process. The process will shift from a batch process to a combination of batch/continuous process. As seen in the literature and summarized in Chapter 2, the process type has a strong influence in the plant's operations and in the applicability of certain lean practices.

**Background of the project**

Today the batches are produced in mixing vessels. During the process, all the necessary ingredients are introduced into the vessels where all transformations occur. From all the ingredients, the binders are the most problematic as their introduction into a batch can lump and coat surfaces causing washout issues.

Mystery project will implement a new manufacturing technology that will bring the following benefits:

- Higher throughput vs today
- Standardization of critical equipment and critical transformations
- Lower cost of formulas
- Increased speed to market

**Technology overview**

The benefits are reached thanks to the new technology. As said before, the new process consists of a combination of a continuous/batch process, leaving the traditional batch lot production used until now. Nonetheless, the current equipment is maintained and serves as a part of the new process. These are the key aspects that promote the mentioned benefits:

- Actual process will be split in two-steps:
    1. Produce base bulk using existing mixing vessels (Batch-process)
    2. Pump the base bulk from the existing vessels to the new equipment where all critical transformations take place in a continuous manner (Continuous-process)
- Some ingredients will be continuously added in the new equipment

## 3.4 Scope of the new manufacturing process

Besides all the mentioned benefits, the reality is that the project raises many operational problems for the plant. Since the project was conceived as a global win-win for all the factories of the company and its benefits globally offset any possible unforeseen costs or unexpected problems, people from manufacturing operations were not involved soon enough in the development of the project. In fact, this factory stands for the plant which has the least of the benefits mentioned before.

It is still uncertain what will be the extent of the challenge that the plant will face with the introduction of the new technology. In particular, the new situation will affect following areas:

- Changeover costs
- Synchronization between material handling and Making
- Synchronization between Making and Packing
- Making Capacity
- Material handling Capacity
- Supply of raw materials to the making equipment
- People operations

It will be important to determine whether these aspects pose a problem that should require further attention or not. An in depth analysis will be conducted in Chapter 5.

# 4 Current state analysis

*"The most dangerous kind of waste is the waste we do not recognize"*

Shigeo Shingo (1909-1990)

Chapter 2.6 has shown how different type of process industries can be identified. Accordingly, different lean approaches should be applied in each particular case. In fact, there is evidence that each company has to be individually studied in order to adapt lean tools to every particular case.

Therefore, Chapter 4 will deal with every aspect of the company that is relevant to the future operations strategy.

Furthermore, in order to be able to measure and understand the impact of the changes coming with Project Mystery in 2016, first a full picture of the current state prior to the implementation is needed.

## 4.1 Portfolio analysis: segmentation

Josef Packowski [PACK14] already highlighted the importance of segmentation while designing an optimal operations strategy. He states that different segments require tailored strategies.

Suggested segmentations consists on differentiating products by different criteria:

- By demand volume using the ABC method
- By the variability of the demand using the XYZ method

The purpose of the next following paragraphs is to classify the product portfolio according to these principles. In order to do so, different data has been gathered from the following sources:

- Historical/Forecasted sales data for every SKU is pulled from business planning file
- Production data for every SKU is obtained from SAP (only historical)

* The fact that sales data is pulled from the business planning file and not from the RCCP is the unconstrained demand information that the former provides, whereas RCCP contains already constrained demand, which is not suited for the purpose of this analysis. Business planning file offers a clear image of the real customer demand.

The analysis has been conducted taking a specific time frame that makes the results the most realistic. This is needed as the demand patterns change relatively fast in the consumer goods industry and therefore, taking an excessive large timeframe might bring to the wrong conclusions.

Consequently, in line with literature suggestions [CHIA15, POOL11], data has been collected as follows:

- Historical data from the past 6 months
- Forecast data for the following 3 months

An initial analysis shows that only 600 SKU's have been active during the studied timeframe. The remaining items, probably have either extremely infrequent demand or have no demand at all.

**ABC classification**

The ABC classification has been conducted based on the demand volume of each of the SKU's. The results are presented in table 7.

| Classification | Volume [MM litres] | % of Volume | # of SKU's | % of SKU's |
|---|---|---|---|---|
| **A** | 143 | 70% | 146 | 24% |
| **B** | 41 | 20% | 153 | 26% |
| **C** | 20 | 10% | 300 | 50% |

Table 7: Results from ABC classification of the product portfolio

Table 6 confirms a common pattern that can be compared to the Pareto Principle or 80-20 Rule. In essence, they say that typically 80% of the benefit is originated by 20% of the items. In this case, 70% of the volume, i.e. 143 MM litres, is originated by only 146 items that account for 24% of the SKU's. Another 153 SKU's accounting for 26% of the total items contribute to further 20% of the volume. Finally, C-products that only represent 10% of the volume are comprised by half of the active portfolio.

A graphic representation of this phenomenon can be found in Figure 11.

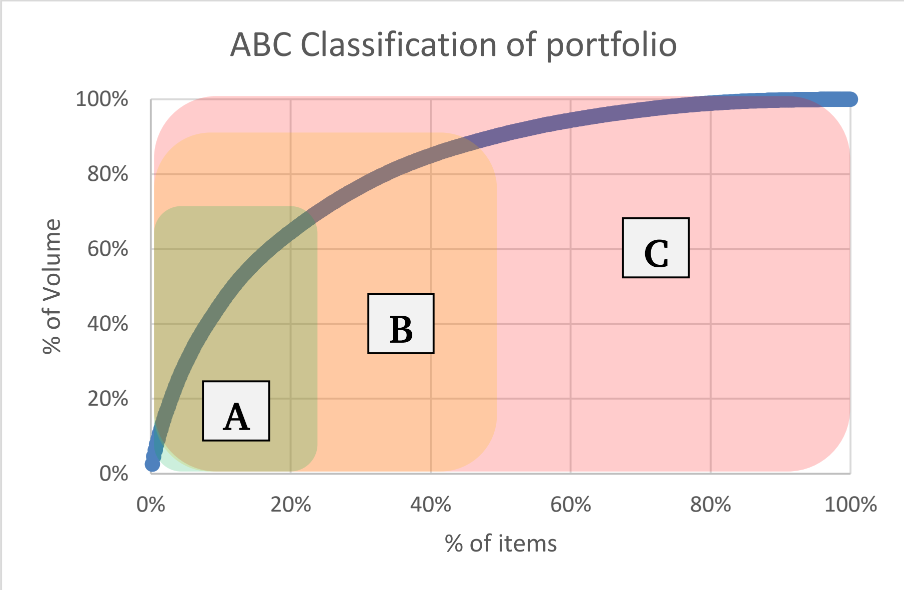



Figure 11: Graphic representation of the ABC portfolio classification

**XYZ classification**

We have seen that the XYZ analysis provides information regarding the variation of demand for particular items by grouping them into 3 categories that contain similar variability characteristics.

One way to measure variability is the so called Coefficient of Variation (CoV), which gives the deviation from average in percentage. It is usually referred as the relative standard deviation.

CoV is defined as:

$$CoV = \frac{st.dev}{average}$$

In order to make this classification it is necessary to delimit a range of variability for each category. While there are different suggestions in the literature of what an appropriate range should be, not all of them are realistic choices for supporting the design of an efficient operations strategy for a manufacturing plant in the process industry. In this case, based on [ZRIL13], the following ranges have been defined:

| | Deviation from the average |
|---|---|
| **X** | Up to 50% |
| **Y** | 50-100% |
| **Z** | Over 100% |

Table 8: Determining XYZ categories [ZRIL13]

These ranges are also consistent with the experienced opinion of several experts within the company.

The results have been summarized in table 9.

| Classification | CoV [%] | # of SKU's | % of SKU's | Combined volume [MM L] | % of Volume |
|---|---|---|---|---|---|
| X | < 50 | 271 | 45% | 132 | 65% |
| Y | 50 - 100 | 151 | 25% | 52 | 25% |
| Z | > 100 | 178 | 30% | 20 | 10% |

Table 9: Results from XYZ classification of the product portfolio

As it can be seen in the previous table, 45% of the SKU’s can be classified as X-Goods products, with a further 25% being classified as Y-Goods. A relative high number of products fall into the category of Z-Goods (30%). However, if we look at the total volumes of the SKU's in each category, up to 90% of the total volume is classified as X-Goods or Y-Goods.

**Combined ABC-XYZ Analysis**

If the data of this analysis is represented in a X-Y coordinate graphic, being the y-coordinate the variability of the demand and the x-coordinate the demand volume, it becomes apparent that there is a high potential to apply different strategies to different product categories. Figure 12 presents the CoV and the average shipment volume in a coordinate axis. The combination of volume and variability information could allow us to reveal further relevant information.

By looking at the graphic, it is possible to confirm visually the previous analyses regarding ABC and XYZ classification.

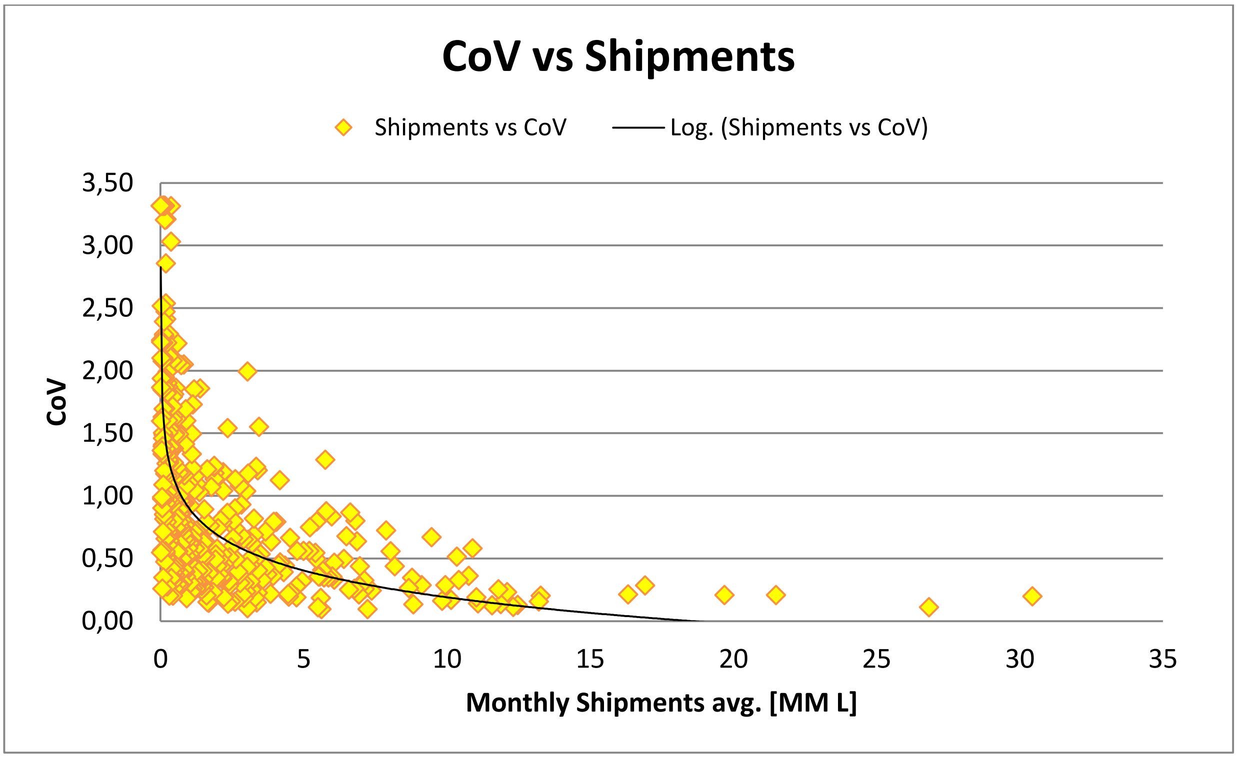



Figure 12: Identifying the demand pattern - CoV vs Shipments

In order to provide a deeper outlook of the analysis conducted through ABC and XYZ classification, it is highly convenient to combine them into an ABC/XYZ cross analysis. With this analysis, additional insights might be revealed.

From the cross analysis we get nine groups of product. Each of these groups could be subjected to different planning and control strategies. The explanation of the main concept behind each group has been summarized in table 10.

| | A | B | C |
|---|---|---|---|
| **X** | • High share in total value<br>• Constant usage<br>• High reliability of forecast | • Medium share in total value<br>• Constant usage<br>• High reliability of forecast | • Low share in total value<br>• Constant usage<br>• High reliability of forecast |
| **Y** | • High share in total value<br>• Neither constant nor sporadic usage<br>• Medium reliability of forecast | • Medium share in total value<br>• Neither constant nor sporadic usage<br>• Medium reliability of forecast | • Low share in total value<br>• Neither constant nor sporadic usage<br>• Medium reliability of forecast |
| **Z** | • High share in total value<br>• Sporadic usage<br>• Low reliability of forecast | • Medium share in total value<br>• Sporadic usage<br>• Low reliability of forecast | • Low share in total value<br>• Sporadic usage<br>• Low reliability of forecast |

Table 10: Fundamentals of a cross ABC/XYZ analysis matrix [ZRIL13]

The following results are obtained when applying the cross ABC/XYZ analysis to the company's demand data:

| **ABC/XYZ Analysis Matrix** | **A** | | **B** | | **C** | |
|---|---|---|---|---|---|---|
| **X** | 101 SKU | 17% | 77 SKU | 13% | 92 SKU | 15% |
| | 105 MM L | 51% | 20 MM L | 10% | 7 MM L | 4% |
| **Y** | 36 SKU | 6% | 44 SKU | 7% | 71 SKU | 12% |
| | 34 MM L | 17% | 12 MM L | 6% | 6 MM L | 3% |
| **Z** | 9 SKU | 1% | 32 SKU | 5% | 137 SKU | 23% |
| | 5 MM L | 2% | 9 MM L | 4% | 6 MM L | 3% |

Table 11: Results from cross ABC/XYZ analysis

AX, AY and BX product account for a large share of all items and volume, 41% and 78% respectively. ABC/XYZ cross analysis has provided very interesting insights such as the fact that there might be potential improvement for the company if a strategy tailoring AX, AY and BX products was developed.

At present, production planning and control activities do not approach any product differently within its work process. Said differently, the company puts similar effort when handling AX-SKU's as well as CZ-SKU's. Consequently, people resources are allocated inefficiently by occupying work time with products that should not deserve same priority as others.

## 4.2 Analysis of the production resources

After having analysed the portfolio, now is the turn to further study the production characteristics in both Making and Packing departments. Chapter 4.2 will serve as a point of comparison for measuring the impact of the project on the plant operations.

### 4.2.1 Overall Equipment Efficiency

At the company, they most used KPI is the Overall Equipment Efficiency (OEE). It gives an idea of how well a process is performing when it is scheduled to run. Essentially, OEE tells us the portion of the scheduled time that the process is adding value to the product. Thus, it is a time-based measure.

To calculate the OEE, the following formulas have been used:

$$OEE\ (\%) = \frac{Net\ production\ time}{Scheduled\ Time} \times 100$$

$$OEE\ Loss\ (\%) = \frac{Downtime}{Scheduled\ Time} \times 100$$

Alternatively,

$$OEE\ (\%) = (1 - OEE\ Loss) \times 100$$

Net production time is defined as the effective time that an equipment produces sellable product. Net production time is also known as Uptime.

Making and Packing are expected to show different OEE results due to the nature of its processes. As we discussed previously, Making shows a batch-type process while Packing consists on a continuous-type process.

According to several sources, OEE values above 85% are considered World-Class [DISH13], [ABEL12].

**OEE Analysis in Making**

Making tracks data regarding downtime losses through an excel-based tool. This is a tool where the operators introduce all the batch-related information for every production run. Every loss is reflected in this file and includes information regarding time, duration and source of the problem.

The tool has been very useful to complete the OEE analysis, making it possible to collect data for every month for the past year. Therefore, the results are based on a 1-year average.

Through the OEE Analysis the following top losses have been identified in Making:

1. Planned Losses
    a. Changeovers
    b. Waiting for storage
    c. Batch preparation
    d. Maintenance
2. Unplanned Losses
    a. Breakdowns
    b. Lack of personal
    c. Shift change

The results have been presented in Figure 13 and show the loss contribution by type of losses, including the aforementioned top losses.

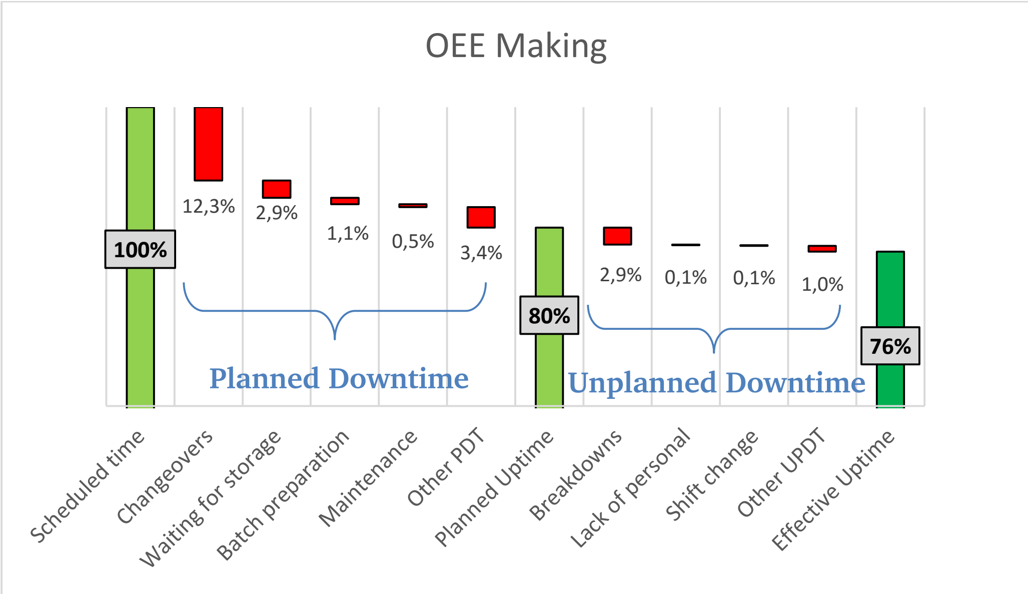



Figure 13: OEE in Making

Achieved results show some distance from the 85% threshold defined as World-Class. As we see in the graphic, main losses are driven by changeovers (12,3%), which is a planned downtime that depends highly on the length of the production runs and on the production sequence. Waiting for storage is another loss dependent on the production plan, as the storage capacity is limited and becomes a constraint if not properly managed. This loss could also be triggered by a low performance in Packing owing to the fact that the containers are not consumed as expected and therefore they cannot be cleaned and prepared for storing a new batch. It represents 2,9% of OEE Loss. In terms of Unplanned Losses, we find that breakdowns represent 2,9% of the losses.

In order to become World-Class, it is necessary to start by reducing the major losses presented in Figure 13. Just changeovers and waiting for storage alone would already prevent achieving 85% OEE. While other significant losses such as breakdowns or batch preparation are already being reduced by Preventive Maintenance and SMED techniques, reducing changeover time losses and waiting for storage have proved to be a hard problem to solve.

**OEE Analysis in Packing**

Packing tracks loss information differently. To required data can be pulled from the computer system, which consists on an internal manufacturing software. The system automatically registers all data for every production run and is already pre-configured to allocate and identify all type of losses. Loss data for the past year has been gathered.

Again, the following top losses have been identified in Packing:

1. Planned Losses
    a. Changeovers
    b. Maintenance
    c. Waiting for bulk
2. Unplanned Losses
    a. Breakdowns
    b. Lack of personal
    c. Material quality

The results have been presented in Figure 14 and show the loss contribution by type of losses, also including the aforementioned top losses.

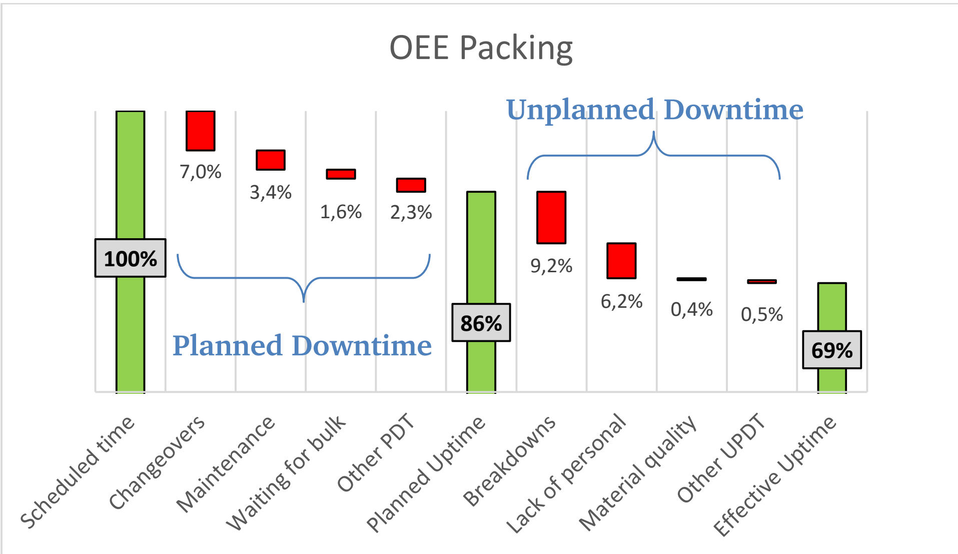



Figure 14: OEE in Packing

As expected, OEE Analysis looks differently in Packing. With a 69%, it is even further from being recognized as World-Class. Changeovers still are an important portion of the losses accounting for 7% but we see how breakdowns (9,2%) and lack of personal (6,2%) have a significant negative impact.

Packaging equipment tend to have more frequent stops than Making equipment. Batch processes in Making are less likely to suffer from breakdowns, as they present less number of moving pieces which are easier to set-up and control.

Lack of personal causes much more trouble in Packing than in Making. Due to the container storage, Packing has certain amount of buffer and as a consequence, a lack of personal in Making does not necessarily cause any losses – Making would simply produce less quantity and catch up in following shifts, thus, no downtime would be registered. However, Packing has a direct impact in case of lack of personal. Set-up, cleaning, changeovers and many other activities cannot be fulfilled in target time when there is not enough people to run the line.

Similar to waiting for storage in Making, waiting for bulk is also linked to the production plan, mainly because of the limited bulk storage capacity. Additionally, it could also be triggered by such a low performance in Making that a required batch is not produced on time.

### 4.2.2 Production capacity on a 7-day operation schedule

Capacity to Demand ratio, C:D is a very common indicator used to highlight the capacity utilization of the installed productive capacity by giving the ratio between the actual output that is being produced and the potential output which could be produced if all the capacity was fully utilized. The company operates on a 7-day schedule and runs all 24 hours every day.

C:D is calculated as:

$$C{:}D = \frac{Max.\,Available\ Capacity\ (Potential\ output)}{Utilized\ Capacity\ (Actual\ output)}$$

The result of this ratio has the following interpretation:

- C:D < 1 means that the available capacity is not enough to cover the demand
- C:D = 1 shows that the resources are fully utilized and producing more is not possible
- C:D > 1 indicates that there is spare capacity and the resources are not fully utilized

According to literature, the average C:D should always be equal or greater than 1,3 in order to cover unexpected variabilities, i.e. demand peaks, poor OEE, future demand increase, etc.

To calculate an average C:D for the Making and Packing departments we have analysed the average values for the past year and a peak month. In addition, a series of assumptions have been made in order to simplify calculations:

- 29 days scheduled per month
- There is a scrap factor of 6% (material loss in vessels and containers)
- Packing average production mix is 55% high speed line and 45% low speed line
- Making OEE is 76%
- Packing OEE is 69%

The results have been summarized in Table 12.

| | Capacity | Average demand | Average C:D | Peak demand | Peak C:D |
|---|---|---|---|---|---|
| Making | 854 Batch | 420 Batch | 2,03 | 742 Batch | 1,15 |
| Packing | 650 MM L | 300 MM L | 2,17 | 530 MM L | 1,23 |

Table 12: Capacity to demand ratio in Making and Packing at average and peak months

The results indicate that both Making and Packing have enough capacity to cover the average demand, with C:D of 2,03 and 2,17 respectively. These values are higher than the 1,3 C:D established limit and it has been proven that even in peak months the capacity has been enough with slightly lower ratios of 1,15 for Making and 1,23 for Packing.

Another insight from the table is that Packing has higher capacity than Making. This is justified by the fact that Packing is responsible for the last transformation process and should always have the highest capacity in order to maximize the plant's output.

## 4.3 Changeover losses: beyond the time-factor

Most of the focus on the shop floor is the minimization of time losses. This has been achieved through a strong OEE improvement culture that is shared by every worker in the plant. While this is truly important and is part of the lean philosophy, process industries are also known for their expensive changeovers.

Changeovers are not only significantly more time-consuming in process industries than in discrete industries, but they also cause higher material losses. Consequently, it is important to analyse them in detail and understand what the main drivers of such losses are. In addition, these other losses might entail higher costs than the time loss itself.

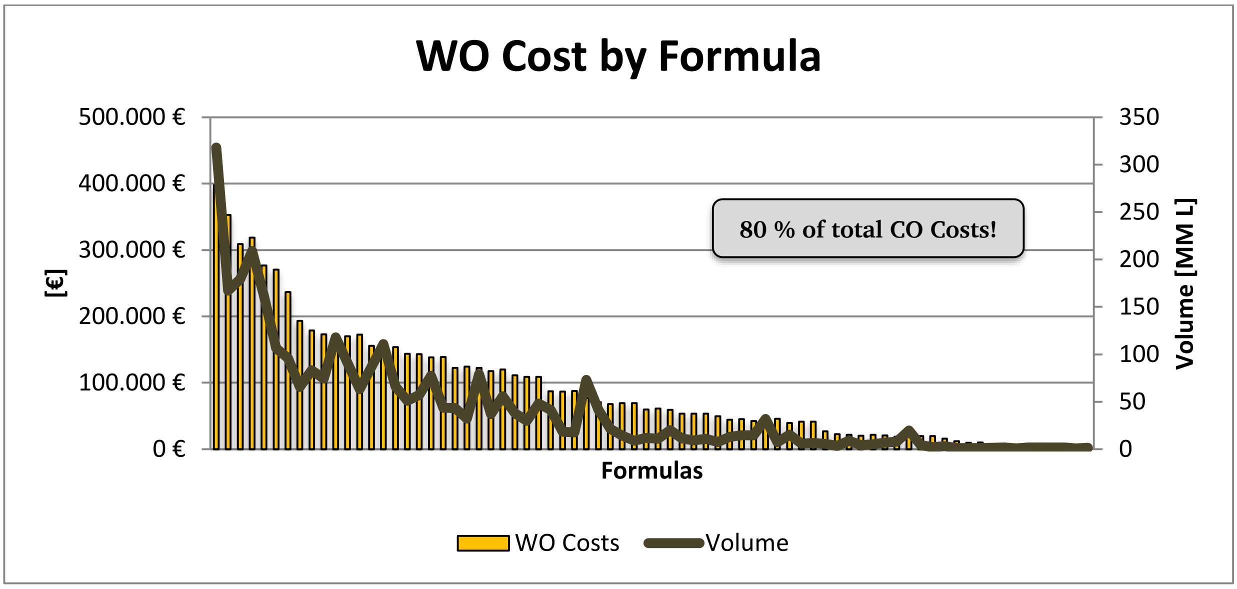



Figure 15: Washout costs by formula

As seen in the graphic, total WO costs are 6,8 MM € per year, which accounts for 80% of the total changeover costs (Making and Packing CO costs combined). The black line represents the volume of each formula during the period considered. If we compare the volume and the WO costs for that particular formula, it is possible to observe different patterns. While some of them are high volume and have high WO costs, others have relative less WO costs in relation with their volume and vice-versa. This means that some formulas perform better/worse in terms of taking advantage of their volume in order to be produced at long/short campaign lengths.

The next paragraphs present a detailed overview of the changeover types that occur in each department as well as a loss calculation.

### Changeovers in Making

A changeover in Making occurs every time that a mixer vessel has to produce a batch of a different formula than the previous one. In such case, the mixer vessel needs to be cleaned. This washout ensures that there is no possible cross-contamination between different batches.

There are different types of washouts, which depend both on the previous and the following formula. They differentiate themselves mainly in 3 things:

1. Duration and amount of water
2. Source of water (City water/DI Water)
3. Destination of waste (Public sewage system/Special treatment)

These 3 aspects have a relevant impact on the water costs. Besides water, other washout costs are the scrap left in the pipes and bottom of the vessel when washing out, energy costs of running the washing equipment and time cost of the operators.

The average costs for 1 washout in Making has been calculated. To do so, information for the past 12 months has been gathered and analysed. See Figure 16 to have an overview of the washout costs.

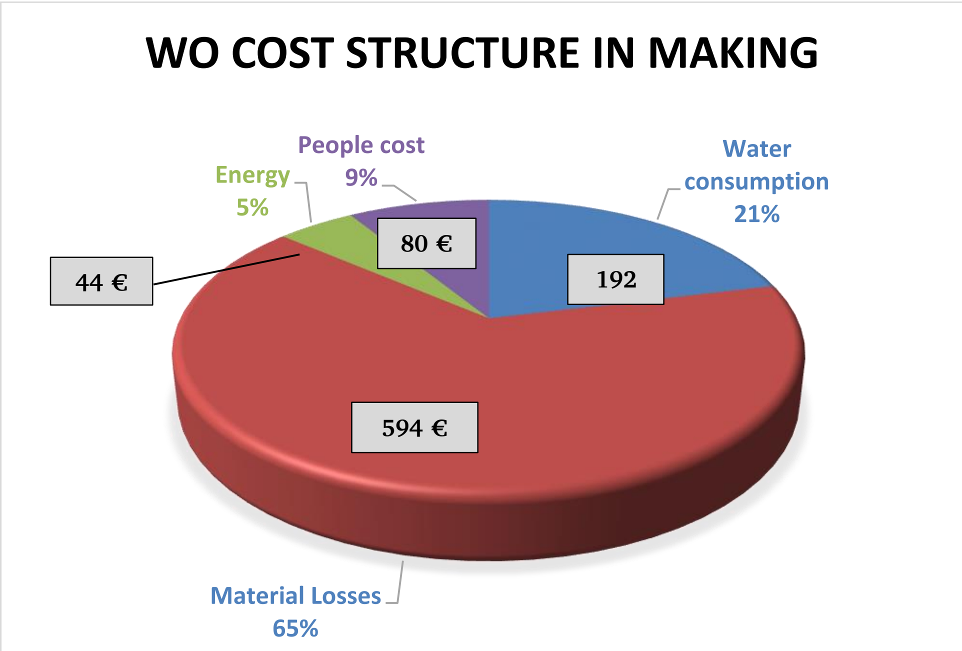



Figure 16: Cost structure of a washout in Making

Notice that scrap is the most significant cost hurt in the washout accounting for 65% of total WO costs. Water costs represent 21%, people cost entail 9% and energy accounts for a small 5%. Altogether add up to 910 € per washout

Figure 16 supports the fact that time loss is only a small part of the total losses caused by washouts in Making.

### Changeovers in Packing

Changeovers in Packing are slightly different and more complex than in Making. We can classify all the changeover types as follows:

- Non-Washout changeover
  - Article change (every changeover implies an article change)
  - Format change
- Washout changeover
  - Washout only
  - Combination of washout and any non-washout changeover

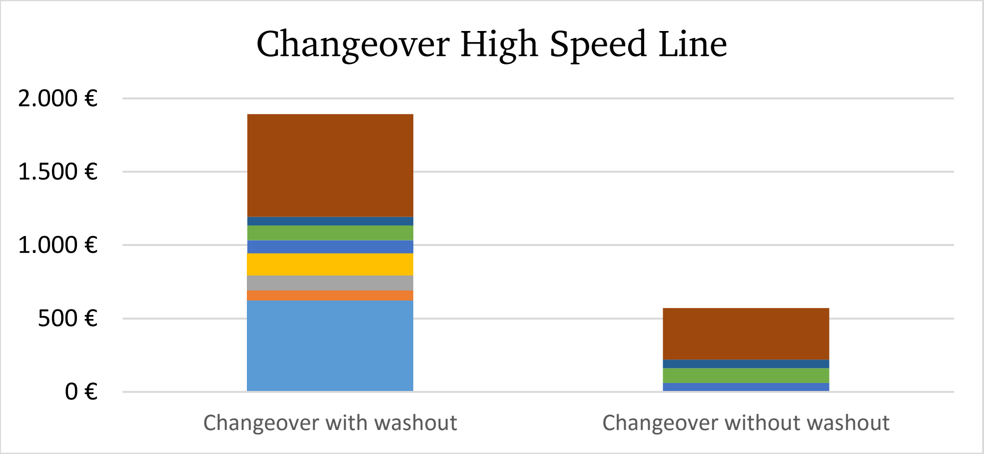
Regarding the changeover costs, the main difference between non-washout and washout changeovers is the presence of water and material losses. In absence of a washout there is no scrap produced (or insignificantly little). That is why there is always the intention to plan long campaigns by grouping different production orders of the same formulation together and sequence them to minimize washouts. This highly increases the planner's efforts.

| | **High speed line** | |
|---|---|---|
| | Production Order with Wash-out | Production Order without Wash-out |
| | [Euro] | [Euro] |
| Material losses in the lines | 624 | 0 |
| Material losses in containers | 70 | 0 |
| Other efforts | 100 | 0 |
| Water cost washout | 150 | 0 |
| People cost for changeover | 90 | 60 |
| Pack material losses | 100 | 100 |
| Administrative order management | 60 | 60 |
| Quality Control cost | 700 | 350 |
| **Total cost** | **1.894** | **570** |

| | Low speed line | |
|---|---|---|
| | Production Order with Wash-out | Production Order without Wash-out |
| | [Euro] | [Euro] |
| Material losses in the lines | 470 | 0 |
| Material losses in containers | 70 | 0 |
| Other efforts | 90 | 0 |
| Water cost washout | 78 | 0 |
| People cost for changeover | 90 | 80 |
| Pack material losses | 100 | 100 |
| Administrative order management | 60 | 60 |
| Quality Control cost | 700 | 350 |
| **Total cost** | **1658** | **590** |

Table 16: Cost overview of the changeovers in Packing

With the information above it has been possible to represent in Figure 17 the costs incurred by the different types of changeover in Packing.



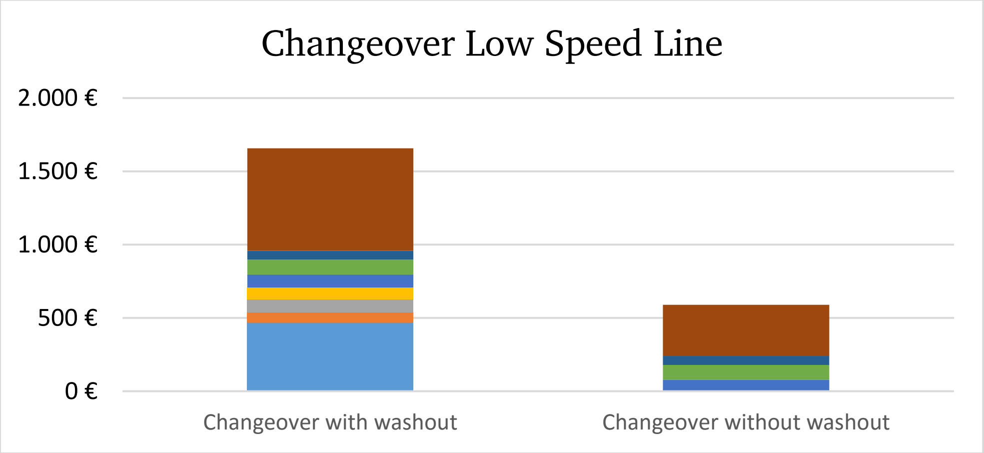




Figure 17: Cost structure of the changeovers in Packing

A changeover with washout is around 232% more expensive in a high speed line (1.894 € vs 570 €) and 181% in the case of a low speed line (1658 € vs 590 €). This numbers are revealing. If one only focuses on the productivity losses of a changeover, it would be no major differences between a non-washout and a washout changeover. Nevertheless, the costs are seriously higher in a washout.

Comparing changeover costs between both departments, it becomes apparent that changeovers with washout in Packing are higher than in Making by 2 times.

In summary, the cost difference between changeovers with and without washout in Packing evidences the need of focusing on reducing the washouts, even at the cost of increasing the changeovers without washout. This only applies if there is enough capacity.

## 4.4 Complexity facts

The company deals with over 1000 SKU's, 40 formulations and over 10 aromas On top of that, packaging variety adds an extra level of complexity. This section tries to graphically represent the packaging intricacy.

There is a series of products that due to its packaging they can only be produced in a single line.

Figure 18 illustrates the line utilization driven only by the SKU's that necessarily require to be produced in that line. Figure 19 shows the amount of different lines that a single formula would need to be produced in. This has a very negative impact due to the fact that a same formula which has to run in several lines result in a high number of washouts.

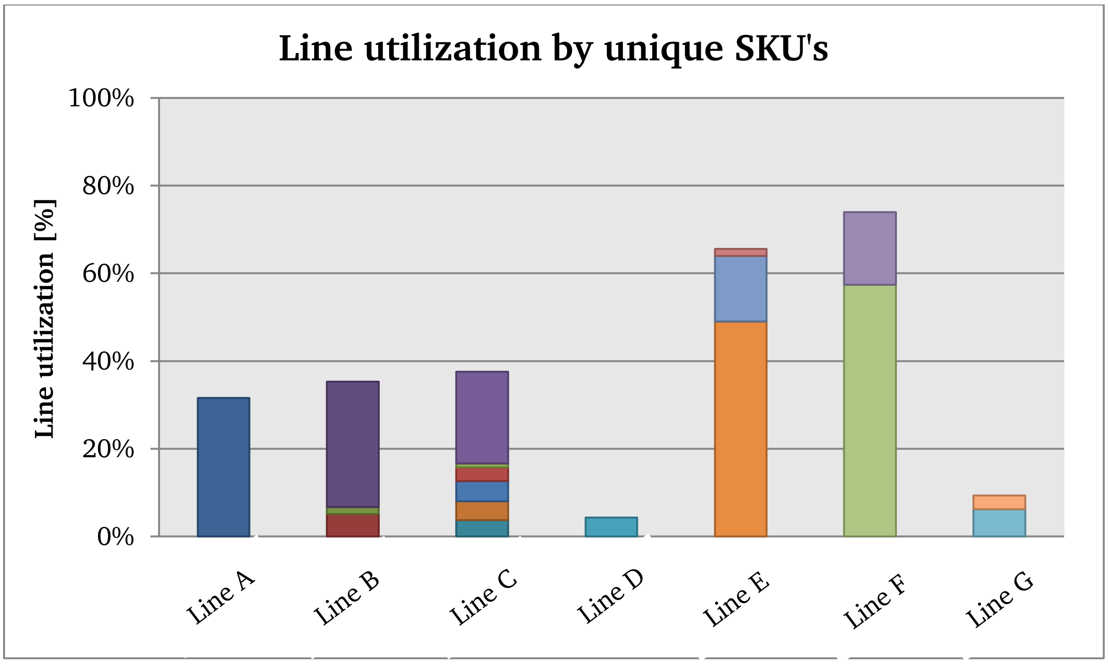



Figure 18: Line utilization by SKU's that can only be produced in a specific Packing Line

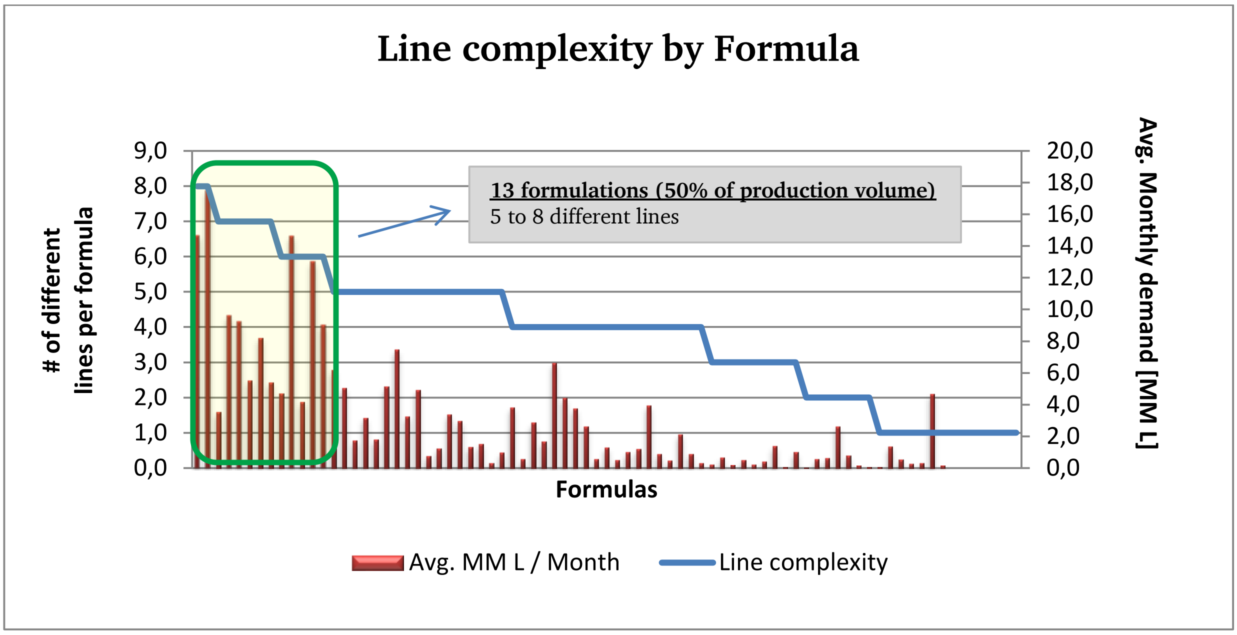



Figure 19: Line complexity by formulation

## 4.5 Average Order Quantity

This section studies the actual average order quantities in each department during the last months.

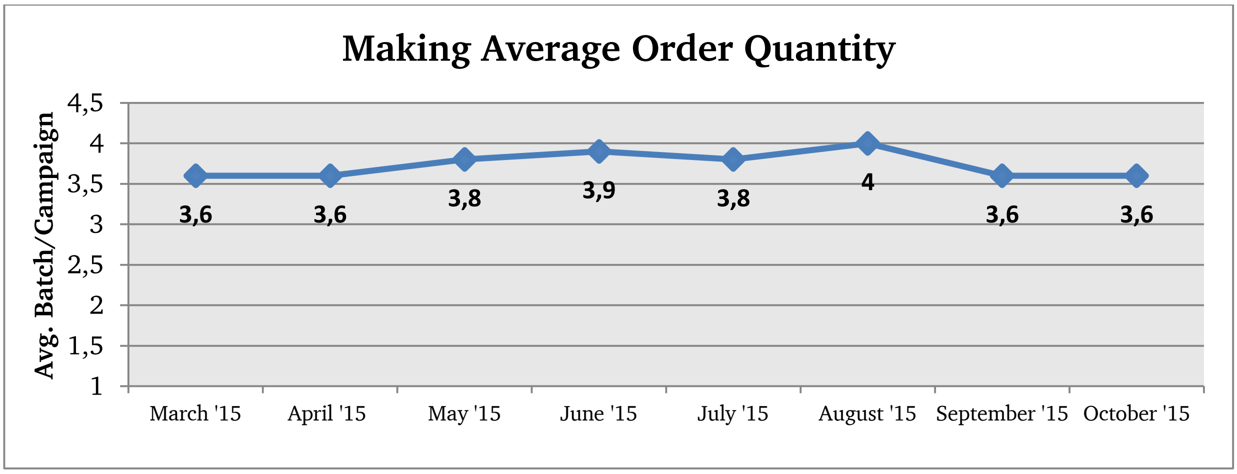



Figure 20: Average Order Quantity in Making

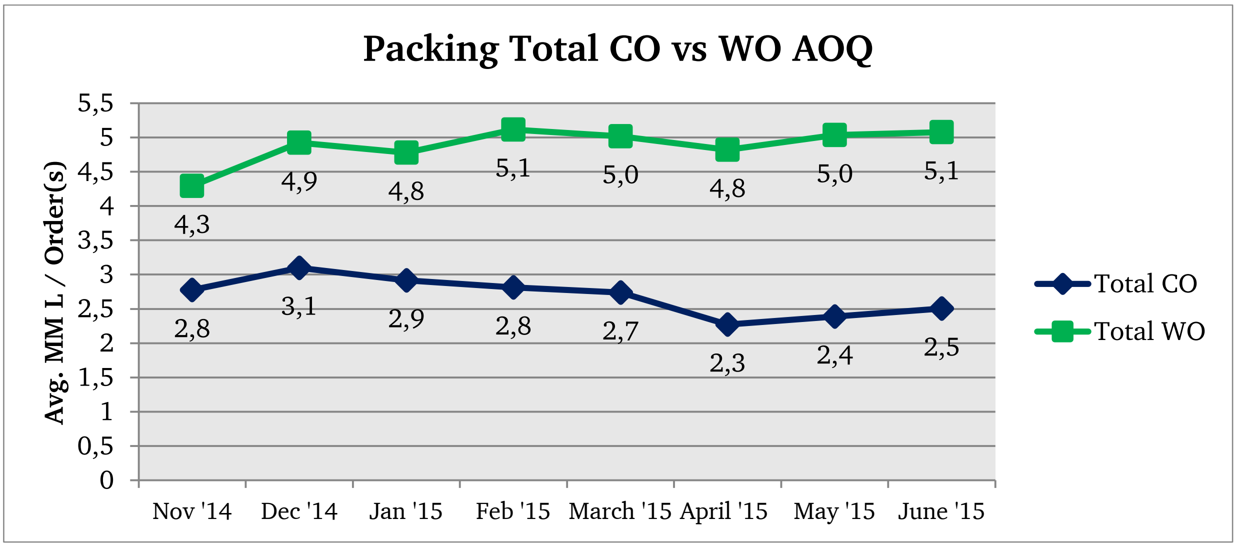



Figure 21: Average Order Quantity in Packing by type of Changeover

It is important to justify the difference between the average order quantity in Making (3,6 Batch) and the WO average order quantity in Packing (4,9 MM L). One might expect that at a formulation level the WO AOQ in Packing would be equal or less than in Making. However, this is not true, as there are several factors impacting the Making AOQ. On one side, it is explained by the lower throughput of one mixer vessel in comparison with a high speed line. This fact forces to produce the same formula in two different mixers simultaneously. On the other side, a second reason is the products with mixed formulations. From Making perspective, such combination is actually two different formulations, requiring a washout between the campaigns of each one of them. Nonetheless, this is not the case in Packing, where the mixed recipes are packaged together.

Total CO average order quantity is at 2,7 MM L at the moment.

**Variability of the average order quantity and campaign distribution in Making**

Despite having a relative constant average order quantity. Continuous problems with intermediate storage have prompted to a further analysis of the distribution of campaigns. The objective of Figures 22 and 23 is to highlight the range of campaign lengths seen in Making that might be causing excessive buffer and blocking too many containers as a consequence.

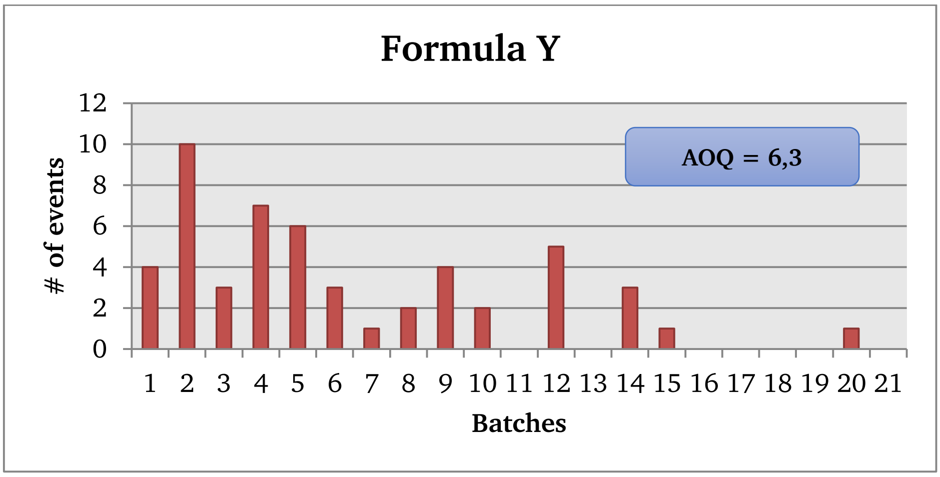



Figure 22: Example of the variability of the order quantity in Making

It is possible to observe that the range of campaign length during the analysed period is quite high, ranging from 1 batch only (4 events) to a 20-batch campaign (1 event). The most repeated campaign length of Formula Y in this period was 2 batches (10 events). This behaviour is not the ideal, as it hurts the intermediate storage capacity and also brings instability to the system.

The same pattern has been found in the rest of the formulas. Figure 22 presents the results of looking at the campaign distribution of all the production in Making. A disturbing fact is that 21% of all the campaigns are comprised by only 1 batch and 23% of 2 batches. There could be a potential improvement in this area.

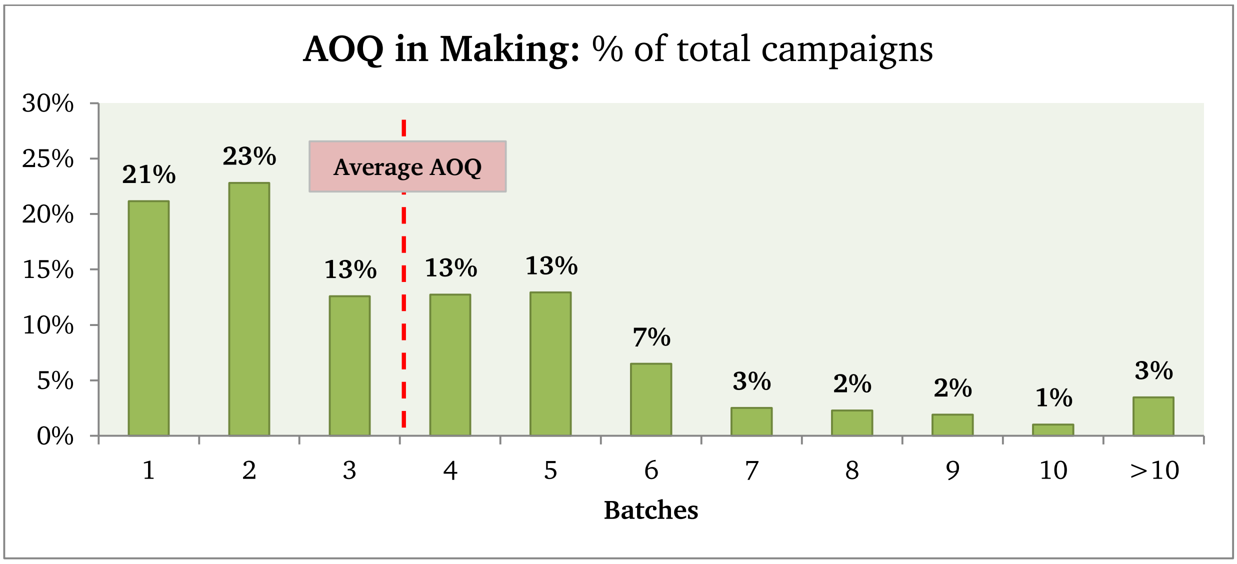



Figure 23: Campaign length distribution in Making

# 5 Future State Analysis

*"If you don't know where you are going, you will probably end up somewhere else"*

Lawrence J. Peter (1919-1990)

Having fulfilled an analysis of the current state and with a good understanding of the actual operations, Chapter 5 will focus on measuring and anticipating the impact of Project Mystery. As quoted by Lawrence J. Peter's, it is utmost important to know where we are going in order to develop an optimal operations strategy under the new scenario with Mystery. Any strategy could be counterproductive if not suited to the new manufacturing process.

Based on the Technical Requirements (TR), the plant is expected to obtain certain benefits from this project. These have been listed in Chapter 3.5 and now we will assess their likelihood of being achieved. To do so, we will focus on analysing Mystery's impact on the following areas:

- Making capacity and productivity
- Material handling system capacity
- Changeovers losses in Making
- Making – Packing Synchronization

The analyses will also serve to test different operations strategies regarding campaign lengths and alternative schedule options. Furthermore, it will be an important input for Chapter 6 in order to develop an optimal strategy.

## 5.1 Mystery: Technical Requirements

The Technical Requirements comprise a series of assumptions reflected in the so called Technical Base File. The values presented in this file contain an estimation of the technical parameters in terms of reliability, quality, sustainability and supply chain synchronization among others. This will serve as the basis to study the impact that Mystery will have on the plant's supply chain. The values are based on the Mystery's Rapid Development Line built in India as well as on the input from the R&D team. They are the basis on which all the targets and expectations have been set for the implementation of Mystery in the plant.

Therefore, the Technical Requirements end up being a guideline of what can be expected from the project and this chapter will test the real impact on the plant's operations by modelling and simulating the future conditions.

Table 17 summarizes the cycle time and expected losses of operating the vessels and new equipment.

| | **Values** | **Units** |
|---|---|---|
| **Cycle Times** | | |
| Vessel CT | 35 | min |
| Vessel WO Time | 15 | min |
| New equipment WO Time | 15 | min |
| **Water and Material Losses** | | |
| Vessel WO Material Loss | 3,3 | kg/WO |
| Vessel WO Water Consumption | 1300 | l/WO |
| New equipment WO Material Loss | 105 | kg/WO |
| New equipment WO Water Consumption | 4000 | l/WO |
| New equipment Interruption Material Loss | 40 | kg/interruption |

Table 17: Technical Requirements for vessels and new equipment

By the time of this work, some values have been verified and re-adjusted through several experimental orders carried out on-site. The confirmed values apply to the vessel CT and WO time, as well as the vessel WO material and water losses. New equipment's values still possess certain level of uncertainty.

## 5.2 New equipment Productivity and Capacity Model

This excel-based model consists on a simulation of the continuous operation of the vessels and the new equipment for an uninterrupted period of approximately 12 hours. The objective is to assess the productivity and the capacity of the whole set of equipment (vessel batches + New equipment continuous process).

The model works in such a manner that it considers in each batch and for every different vessel whether a washout is needed or not, based on the campaign length and the formula that has run before. It also considers the material flow and physical connection between the vessels and the new equipment, so that a downtime in the vessels affects the new equipment and vice versa. The model is also capable of obtaining results as a function of campaign length thanks to the use of Macros.

The inputs needed for the model are:

- Range of campaign lengths to consider
- Vessel Cycle Time
- Vessel Washout Time
- New equipment Washout Time
- Pump-out time between vessels and new equipment
- Other Planned and Unplanned Downtimes

Figures 25 to 31 show the results of the Model. Figure 25 is a representation of the expected new equipment's throughput and OEE as a function of the campaign length. Figure 26 and 27 display the implications of that throughput in terms of capacity to demand ratio. Besides that, they also give an overview on the possibility to reduce the plant's operations to 5 days a week instead of the actual 7 days.

Finally, a dedicated section has been used to study the consequences of not meeting the Technical Requirements.

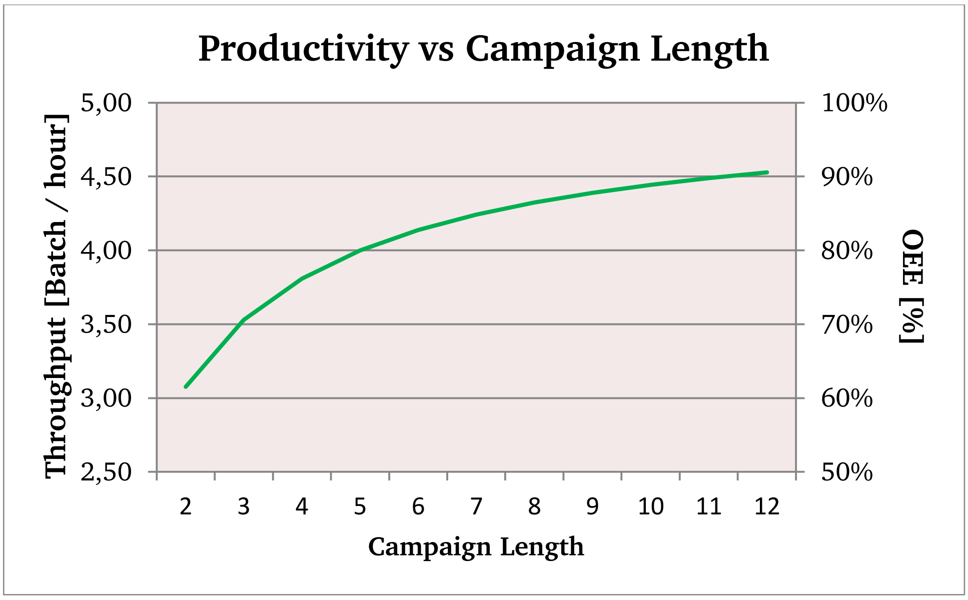



Figure 25: New equipment's productivity as a function of the campaign length

The model shows how there is a decreasing effect of the productivity improvement at long campaign lengths. We have seen that the current average campaign length in Making is approximately 3,5 batch per campaign. If nothing would change in the production planning, we would expect about 73% OEE at 3,65 Batch/hr. The benefits of increasing the average campaign length from the actual 3,5 are in fact high.

To represent the expected capacity, we have reduced the range of campaign lengths to 3, 5 and 8 batch per campaign. These values correspond with a realistic scenario on the short- and medium-term

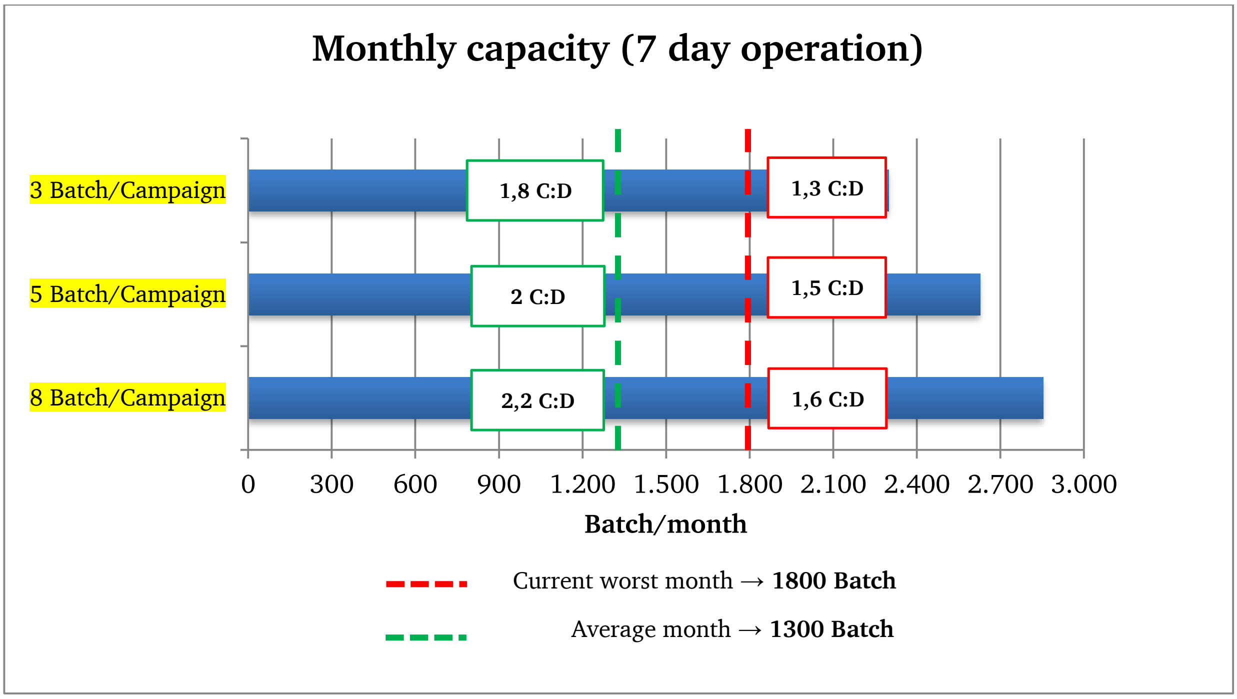



Figure 26: Mystery's capacity on a 7-day operation as a function of campaign length

We have seen in chapter 4.2 that the actual C:D ratio in Making is 2,03 at an average month and 1,15 at a peak month. As we see in Figure 25, with Mystery, at an average campaign length of 3 batches we expect a ratio of 1,8 at an average month and 1,3 at a peak month. If the average campaign length increases to 5 or 8, then we observe a ratio of 2 and 2,2 respectively at an average month while at a peak month it would be ratios of 1,5 and 1,6. This results demonstrate sufficient capacity in every scenario on a 7-day operation schedule.

Next Figure shows what would happen if the department reduces its working time to 5 days a week.

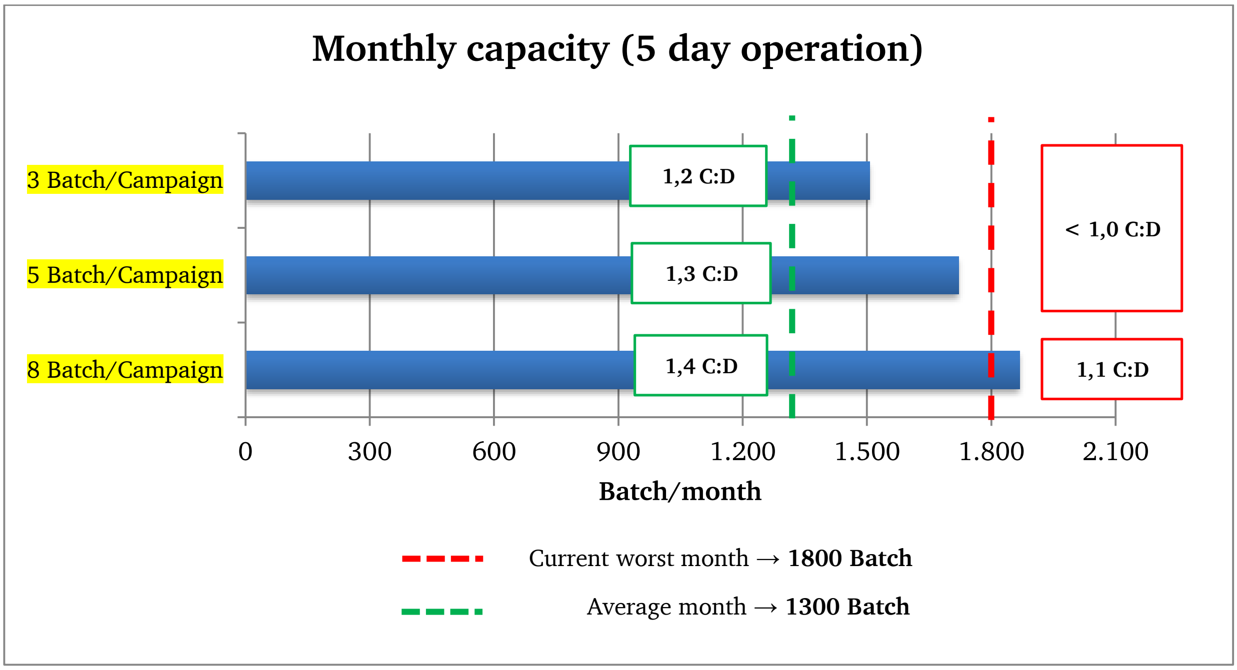



Figure 27: Mystery's capacity on a 5-day operation as a function of campaign length

The conclusions of Figure 27 differ from the previous case. At 3 batches per campaign C:D is a tight 1,2 at an average month. At 5 batch per campaign the ratio only increases to 1,3, a value commonly accepted as sufficient. However neither of both mentioned cases would be enough to cover the capacity at peak months. To cover this peak demand, a rise in the average campaign length up to 8 batch per campaign would be needed in order to reach a 1,1 C:D.

Figure 27 has revealed an interesting opportunity for the company. During months in which the demand is average, Making could operate only 5 days a week thanks to Mystery. Obviously, feasibility needs to be studied, particularly regarding mobile storage and possible labour issues such as how much time in advance can the department agree with the employees that it will operate on a 5-day operation schedule for a certain period. The issue with intermediate storage will be addressed in section 5.3.

### 5.2.1 Deviations from TR: Sensitivity Analysis

What would happen if the Technical Requirements estimates are not met? How would this affect throughput? Figure 28 to 31 show the impact of a variation in the cycle times of different parameters and give a clear image of which parameter is the most or least sensitive.

To analyse it, the Model has been used with alternative inputs that have been summarized in Table 18. To avoid mixed results and give more clarity about each parameter, for every scenario there is only one parameter changed while the other parameters remain as the reference indicated by the Technical Base File.

| **Input Parameters** | *1* | *2* | *3 - Reference Input* | *4* | *5* | *6* |
|---|---|---|---|---|---|---|
| CT[min] | 25 | 30 | 35 | 40 | 50 | 60 |
| Cleaning POT [min] | 5 | 10 | 15 | 20 | 30 | 35 |
| Cleaning new equipment [min] | 5 | 10 | 15 | 20 | 25 | 30 |

Table 18: Selection of parameters to analyse the sensitivity in front of unexpected variances in Mystery's cycle times

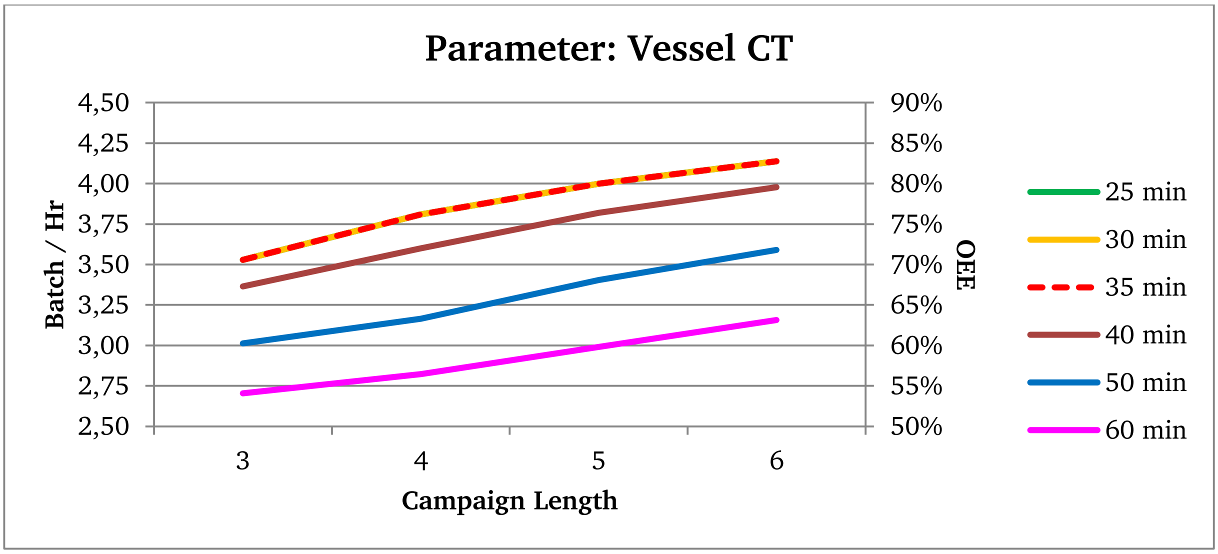



Figure 28: Impact on productivity of cycle time variations in the parameter "Vessel CT"

Some curious information can be extracted from Figure 28. Notice that the green, yellow and red dotted line are simply overlapped in the same position. The graphic indicates that improving CT below 35 minutes would bring no benefit to the system's throughput at all.

Nevertheless, if the CT was worse than expected there would be a significant drop in the productivity.

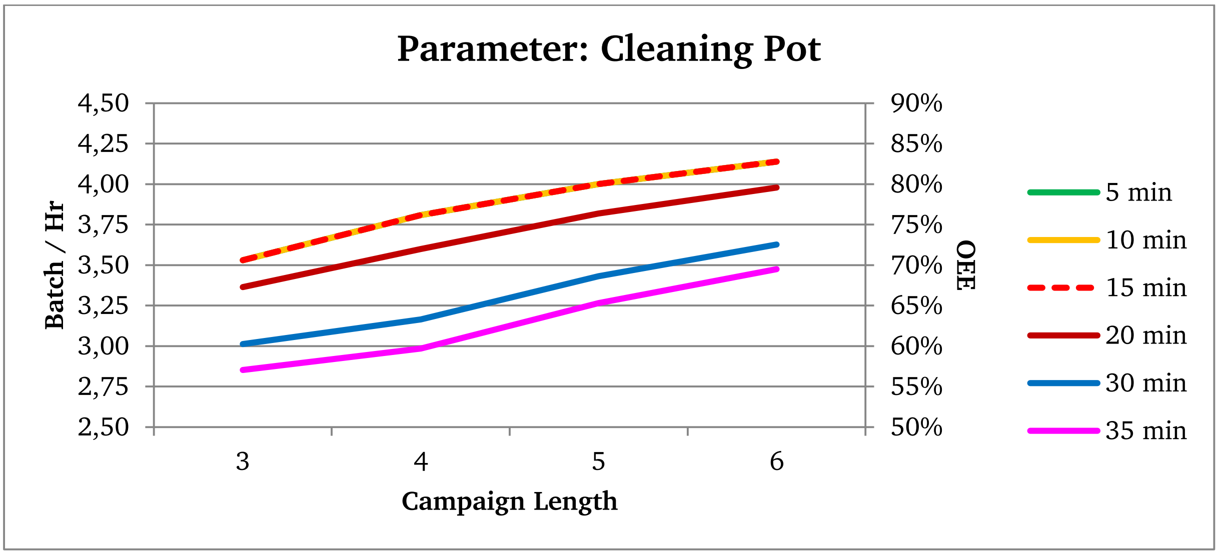



Figure 29: Impact on productivity of cycle time variations in the parameter "Cleaning Pot"

The second parameter analysed is the washout time in the mixer vessels. Similar to the previous case, there is no improvement potential in times below 15 minutes. In case of times above 15 minutes, we see a clear throughput decrease.

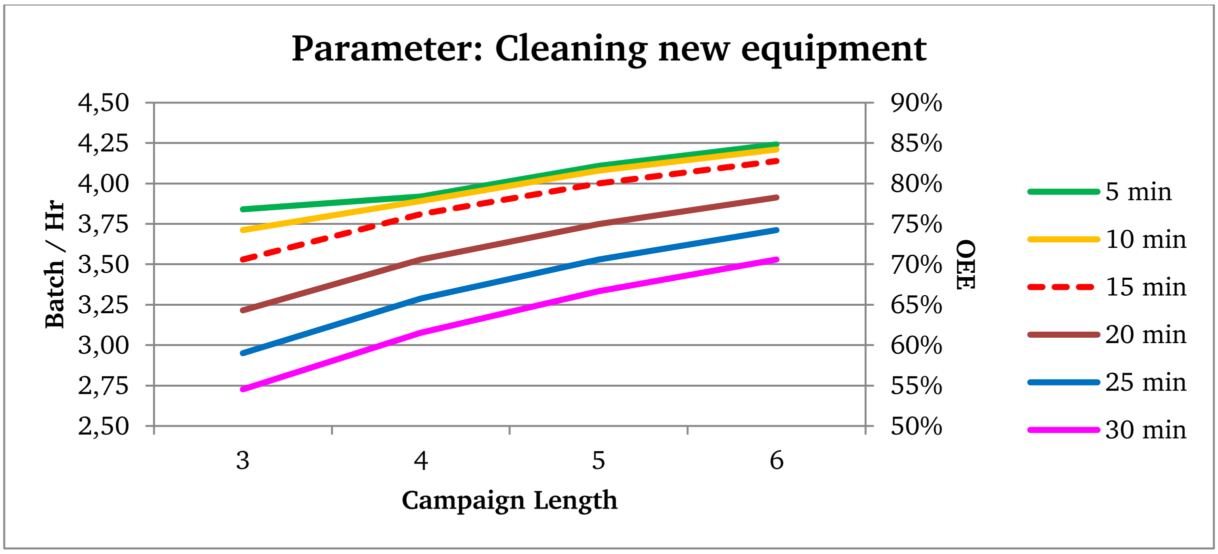



Figure 30: Impact on productivity of cycle time variations in the parameter "Cleaning new equipment"

Finally, Cleaning new equipment shows a different behaviour than the former two parameters. Interestingly, an improvement in the washout duration of the new equipment brings some benefit to the system's output. This is explained by the fact that Cleaning new equipment has proved to be the bottleneck of the making process. Therefore, any improvement in other parameters has shown no improvement as opposed to Cleaning new equipment.

To sum up, the sensitivity analysis has measured the risks of not fulfilling the expectations set on the Technical Requirements. It has revealed that Cleaning new equipment is the bottleneck under the base conditions and therefore it deserves to be a top priority by ensuring that the target time of 15 minutes is met or improved.

The model has also shown that there is a high synchronization between mixer vessels and new equipment, causing few downtimes and proving that the configuration of 4 vessels for 1 piece of new equipment is the right one – 3 vessels would have been insufficient, causing long downtimes and 5 vessels would have caused no positive impact, as the bottleneck would have remained in the washout of the new equipment.

**Example of a real risk: Pre-weigh issue**

During the making of this model it has been found that there is a real risk that challenges the target CT of 35 minutes. It is something that had not been foreseen at the development phase: Pre-weigh of liquids.

The fact that today a whole campaign is produced by the same mixer, allows that the process of pre-weighing can be carried out simultaneously while the mixer vessel is still finishing the previous batch. It is only when a new campaign needs to be produced in that mixer, that a washout prevents the pre-weigh equipment to start weighing any liquids until the washout is completely finished.

However, with Mystery that will change. Even at long campaigns, they are produced in sequence by different mixers. Therefore, very few times the pre-weigh process will start simultaneously. For example, at a campaign length of 4 batches, it will never be possible to pre-weigh simultaneously.

In Figure 31 it is possible to see how this will affect the system's throughput.

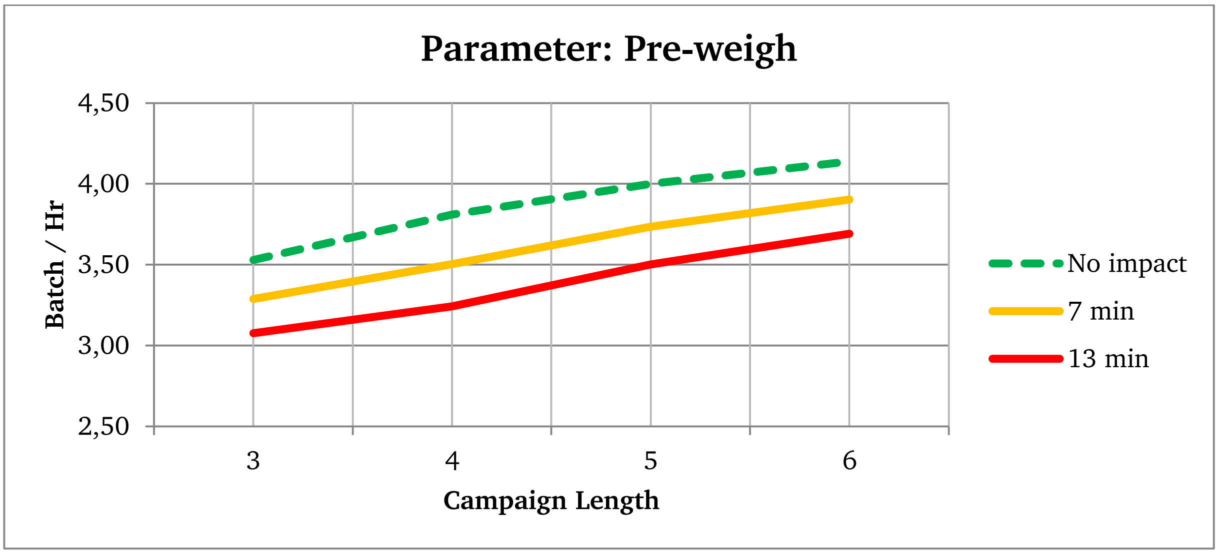



Figure 31: Impact on productivity of cycle time variations in the "Pre-weigh" process

No impact would mean that the pre-weigh starts soon enough that causes no downtime (green line). Whereas, the red line means a 13-minute delay, which is the average required time to pre-weigh the liquids. An intermediate scenario has been represented (orange line). The graphic shows that longer campaigns barely offset the negative impact of a pre-weigh issue. The loss between the base scenario and a 13-minute delay can result in a 0,5 batch/hr rate loss. In terms of OEE, that would mean about 10% loss.

This issue requires a technical solution in order to allow simultaneous pre-weighing even when there is a washout.

## 5.3 Material handling system Capacity Model

The implementation of Mystery creates some doubts regarding the material handling system capacity. While it is clear that with the binder removal the overall capacity will increase, there are some concerns related to the instantaneous capacity due to the increased throughput in the making process that might lead to instantaneous bottlenecks.

The Capacity Model is an excel-based simulation that calculates the new capacity under Mystery's scenario. To do so, it considers the following inputs:

- Demand aggregated to Formula level
- Scheduled time
- Component order of addition by Formula
- Layout – component locations
- Component feed rates
- Other (movement speed, load/unload times, etc.)

The layout and the component order of addition are necessary to simulate movement times. The order of addition indicates which component has to be filled and in which sequence, as the components cannot be mixed in any form. The absence of binders in this step of the process will play a fundamental role.

As a result, the model is able to return the following outputs:

- Capacity to demand ratio
- Feeds/year by component
- Trolley build time by formula
- Optimal layout improvement
- Instantaneous capacity in 2-hr time windows

In terms of overall capacity increase, the binder removal will release 33% extra capacity from a 1,66 C:D to a 2,22 C:D ratio. The results have also proved the model's validity by confirming the actual C:D ratios seen in the material handling system at the present. See the summary in Table 19.

| | C:D | Comments |
|---|---|---|
| **Current State** | 1,66 | This result validates the model – good estimation of today average month |
| **Top Month (Current)** | 1,37 | Good estimation of a current peak month (but need double check instantaneous bottlenecks) |
| **Mystery I** | 2,10 | Sufficient capacity with Mystery – initial phase |
| **Mystery II** | 2,22 | Sufficient capacity with Mystery – final |

Table 19: Capacity Model results

Figure 33 gives an overview of the trolley build time reduction achieved by the removal of binders.

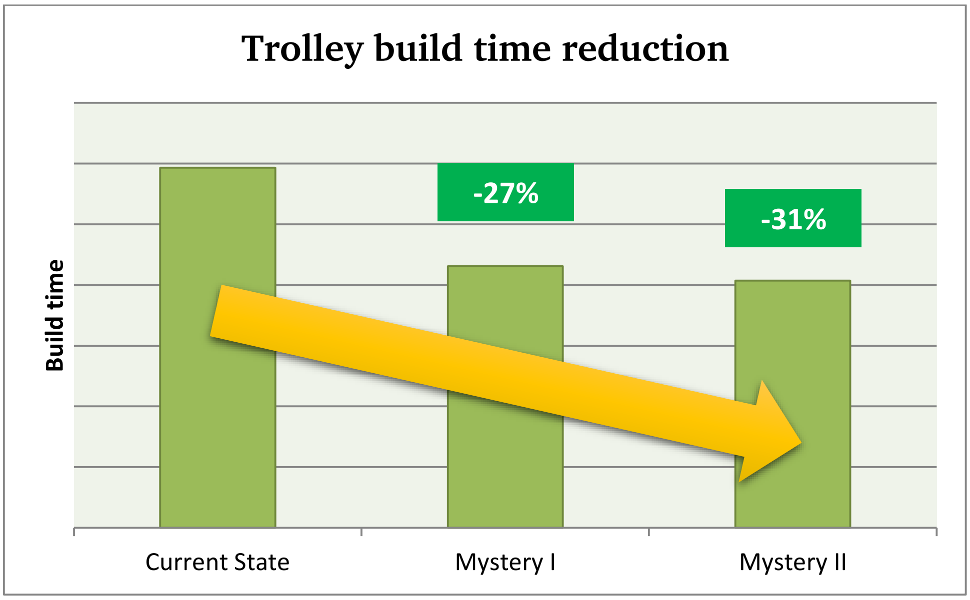



Figure 33: Trolley build time reduction after binder removal

The results evidence up to 27% build time reduction with the new equipment operating without a few Formulas and up to 31% when fully operational.

**Instantaneous capacity concerns**

Despite an overall capacity increase, there are some concerns when looking at the instantaneous capacity. This is supported by the fact that in peak months where the C:D ratio was 1,37 the plant suffered from several interruptions driven by instantaneous bottlenecks in the material handling system. So, why if the C:D was sufficient did the company experienced downtime due to a material handling system bottleneck?

The main reason behind it seems to be the short-term accumulation of formulas in production that require one or more trolleys with high trolley build times. This could be the case of a group of Formulas that require 3 different trolleys.

To prove our assumption, the model has been used to display the course of the "instantaneous" C:D ratio over short periods of time.

Figure 34 represents the current state. Every unit of the X-axis represent a 2-hour time fence, meaning that the (x,y) value is giving the particular C:D ratio during those 2 hours. High spikes need to be omitted because they indicate a very low utilization of the material handling system for a particular 2-hour interval and do not reveal any useful information.

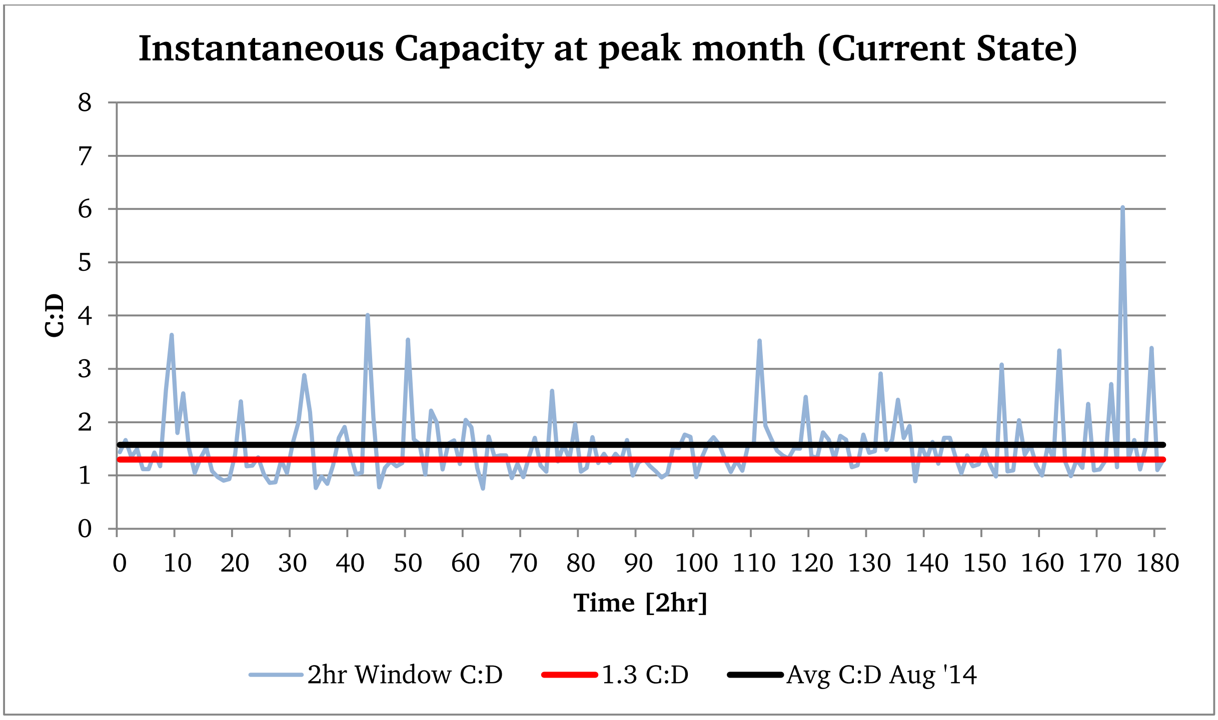



Figure 34: Instantaneous Capacity at peak month – current sate

The simulation clearly confirms that the average C:D ratio in August ’14 was over 1,3. However, as suspected the instantaneous C:D has dropped under 1,0 on several occasions. Such events are probably linked to the downtime events suffered during that peak month. In fact, the simulation shows that there were in total 43 2-hour intervals where the C:D dropped below 1,15 while the real data of August ’14 indicates a total of 42 downtime events caused by a bottleneck in the material handling system.

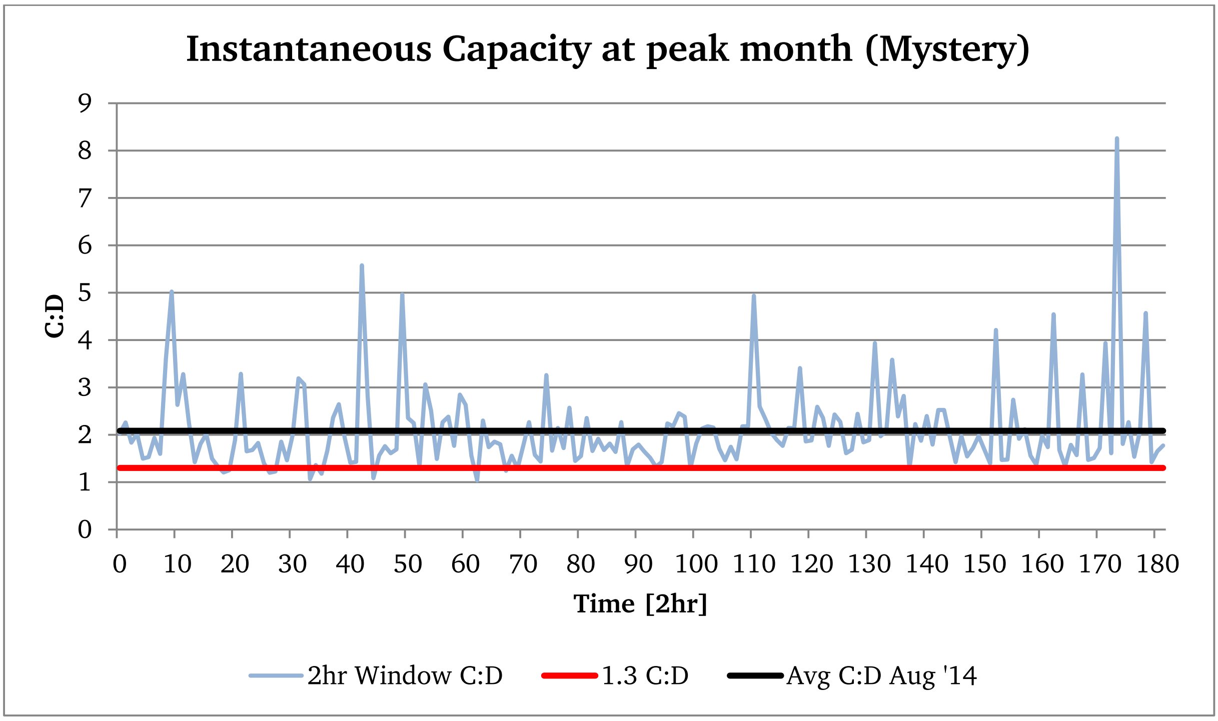



Figure 35: Material handling system Instantaneous Capacity at peak month – with Mystery

The results for the scenario with Mystery have been represented in Figure 35. Here we can observe that the same peak month would have been managed with a C:D ratio of 2,1. The interesting part is that the model manifests evidence that the instantaneous capacity to demand will not reach values below 1,0 and just a few occasions below 1,3.

In summary, according to the Capacity Model, it is possible to affirm that material handling system capacity will increase 33% and instantaneous capacity will no longer be a concern. Nevertheless, there is one risk worth to mention. The risk of the interruption of the new equipment. An unplanned stop of this equipment implies 40 kg material scrap due to ramp-down and ramp-up processes.

To protect against such unplanned events, it might be necessary to consider some measures such as:

- Full campaign trolley pre-build to guarantee no interruption during a campaign
- Visual notification to the operators ensuring enough time to pre-build trolleys and avoid interruptions

Model's outputs offer several additional opportunities that have not been studied in detail. These include:

- Assistance in the decision of new optimized screw diameter sizes based on the average and range of the feeding quantity
- Iterative approach to obtain the optimal layout that minimizes travel times based on position and frequency of feeding
- Support the selection of raw material packaging size (small bags/big bags) according to the frequency of container replenishment

## 5.4 Mystery's changeover costs

An additional discussion area concerns the amount of changeover losses in comparison with today. A representation of the water and material losses as a function of the campaign length can be seen in Figure 36.

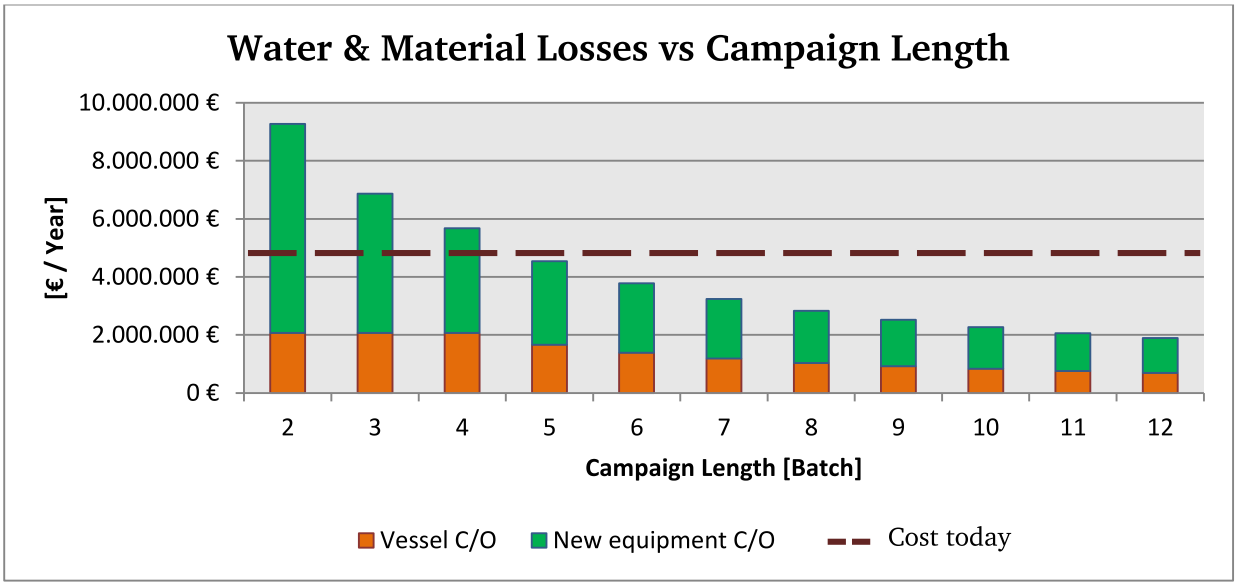



Figure 36: Water and material losses as a function of campaign length

Current costs of around 5 MM € per year are expected to increase at average campaign lengths below 5 batches. As from 5 batches, the costs are offset by the lower number of washouts. This chart also differentiates the behaviours of washout costs in the pots and in the new equipment. On one side, the four mixers do not benefit from any increase in campaign length below

4 batches, as they would need to be cleaned anyway after every batch. However, at campaigns of 5 batches or above we see an increasing cost reduction. On the other side, the new equipment progressively benefits from longer campaigns. Overall, this graphic shows a decreasing incremental benefit at long campaigns.

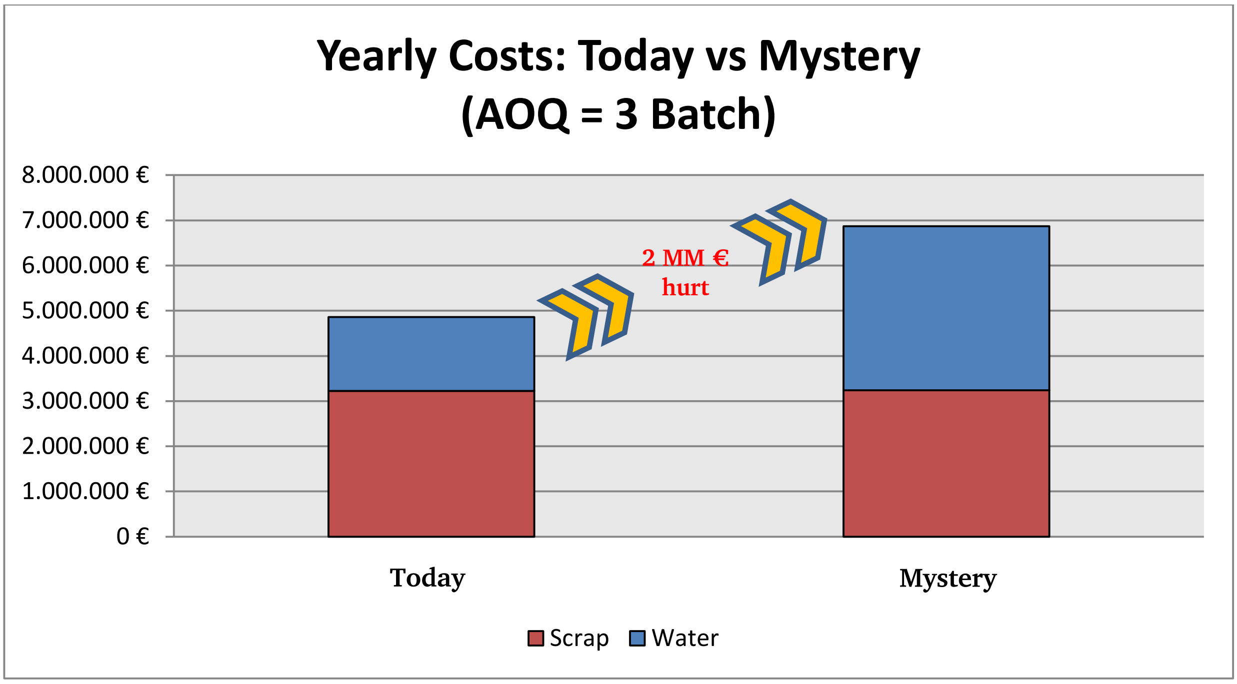



Figure 37: Comparison between washouts costs: Today vs Mystery

A closer look to the cost differences between today and Mystery reveal a cost hurt of approximately 2.000.000 €/year mainly because of the higher water consumption which entails more than double the amount of litres per washout than today. Essentially, a washout with Mystery at an average campaign length of 3 batches (today = 3,6) is 40% more expensive.

## 5.5 Interim storage capacity: Flow simulation

Containers for intermediate storage are already a recurrent issue at present. The limited space in the plant is a very strict constraint that has limited the maximum number of containers to 84 units.

From the 84 containers, we need to consider that there are usually about 15 blocked for production and up to 5 additional are blocked for quarantine. That leaves an effective available number of containers for storing and buffering of 64 containers.

The modelling of the storage capacity has required the use of a specific software for simulating flow between Making and Packing under the consideration of the limited intermediate storage. The software used allows a full parametrization of the production interfaces - Making, intermediate storage and Packing in this case. The software is an internal solution of the company.

As usual, first of all a validity test has been conducted. The software runs up to 50 schedules and the results regarding storage capacity can be seen in Figures 39 and 40. The first one is the distribution of container usage over time. For example, in Figure 39 we see that around 20% of the time the container usage is in the range of 20 to 25. The second figure shows the maximum and the average container usage at each one of the 50 simulation runs.

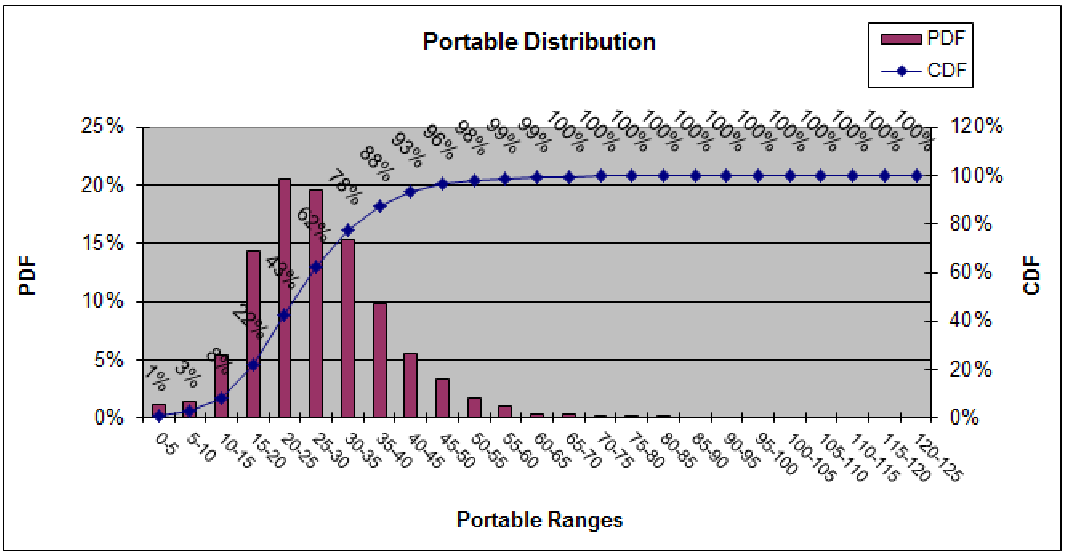



Figure 39: Flow simulation – Current state simulated distribution of container usage

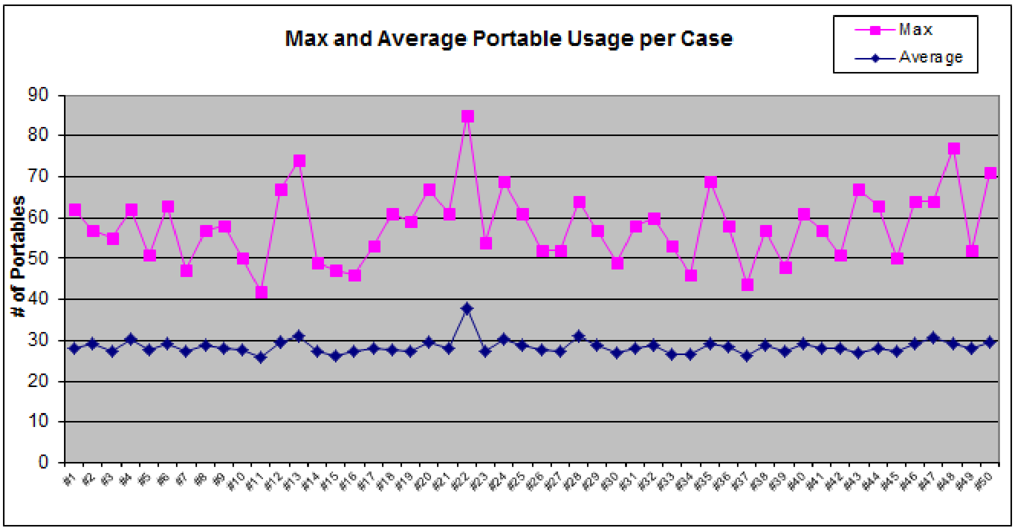



Figure 40: Flow simulation - Current max. and average container usage

From the two graphics above we can deduce that currently we should not have any problems on average, but certain peaks are expected. Specifically, at 1% of the time we should face a storage bottleneck. If compared to reality, this results seem rather optimistic. However, there is an explanation for that. Most of the times the storage capacity problems are driven by an unusual bad performance of Making/Packing or a poor production planning that schedules a formula that will not be packaged shortly.

Such cases of poor performance of Making or Packing typically add an exceptional buffer of 5 to 10 mobiles. In the scenario analysis of Mystery an extra 5-10 mobiles of uncertainty will be considered.

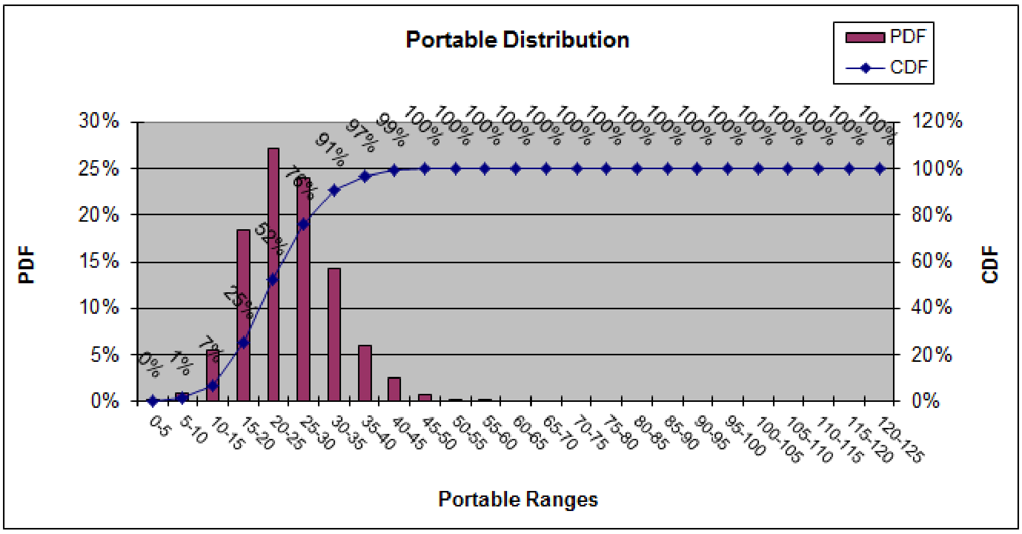



Figure 41: Flow simulation - Simulated distribution of container usage with Mystery

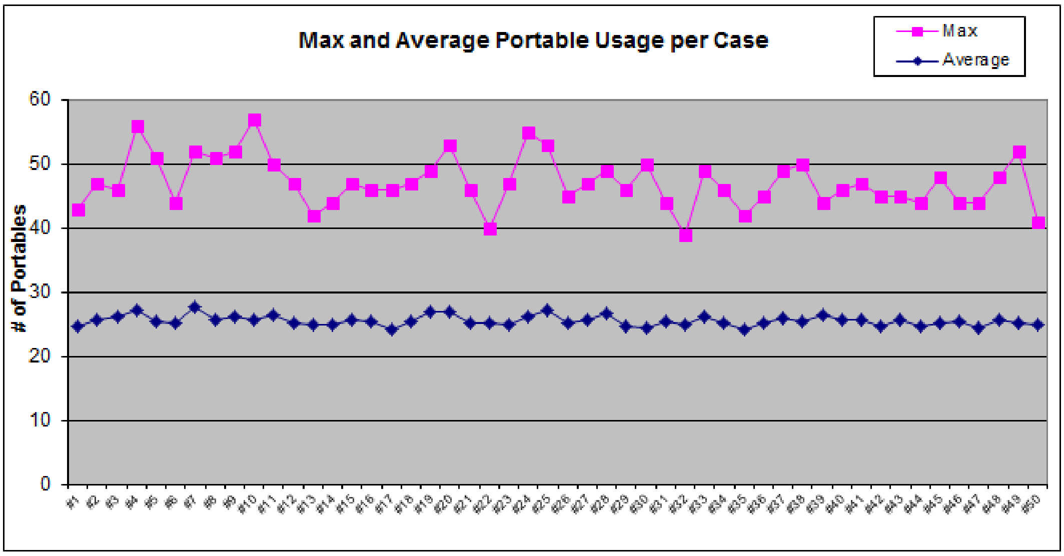



Figure 42: Flow simulation - Max. and average container usage with Mystery

The model indicates a slightly better performance with Mystery. It shows a shorter distribution tail (Figure 41) with an average consumption of 25 containers, which is 5 containers less than at present. In terms of maximum usage, the spikes do not reach 60 containers and barely 2 simulation runs showed peaks of 55 containers. Thus, with these results and even considering the 5-10 containers of uncertainty, it is less likely to suffer from container shortage in the future.

However, the nature of Mystery implies some risk. Whilst at present any campaign can be interrupted and be hold until it can resume or be cancelled at all without extra losses, Mystery does not work like that. Once a campaign starts, an interruption would cause several losses and the trolleys for all the involved batches would be already prepared.

In order to avoid the negative impact of that, the new operations strategy will need to set a limit of campaign length. Very long campaigns that have been seen the last years with a few high volume formulas (record of 90 uninterrupted batches) entail an excessive container usage and can lead to interruptions in the new equipment. Consequently, the behaviour observed in Chapter 4.5 needs to be corrected.

**Container capacity at a 5-day operation schedule**

Following the prior analysis, the simulation has been repeated but at a 5-day operation schedule. The model assumes that Packing still operates 7-days a week. The results can be seen in Figures 43 and 44.

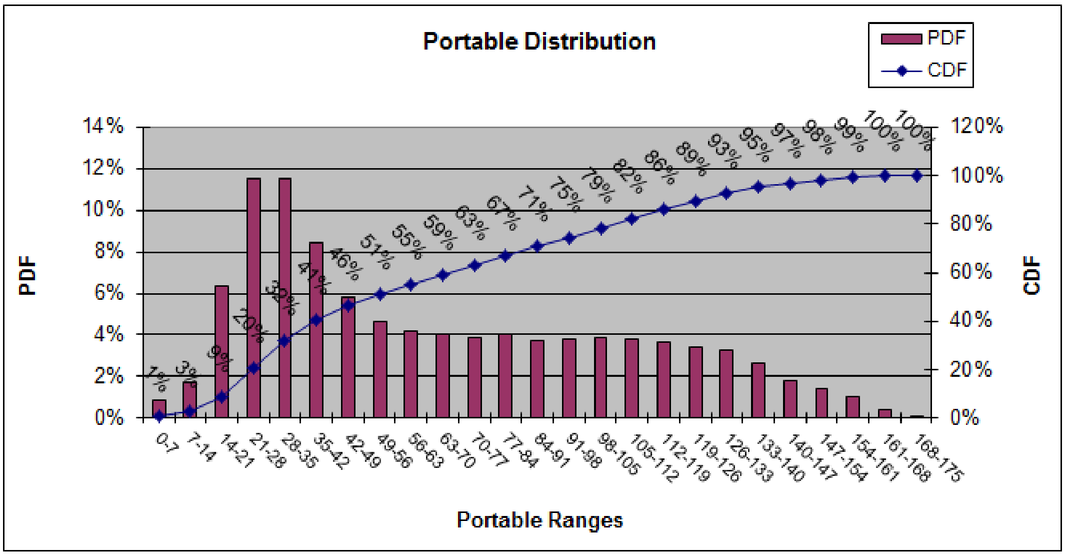



Figure 43: Flow simulation – Distribution of container usage with Mystery at a 5-day operation schedule

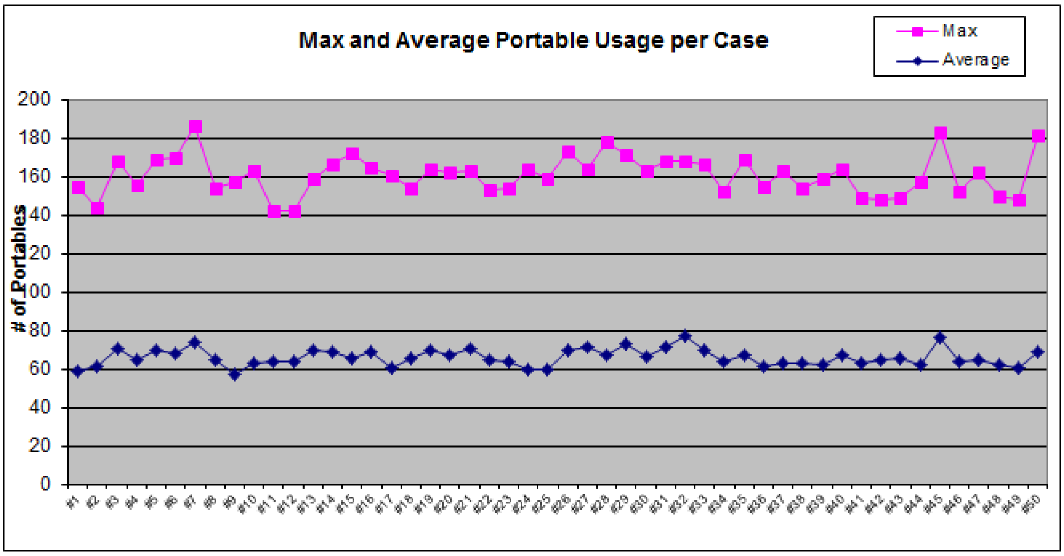



Figure 44: Flow simulation - Max. and average container usage with Mystery at a 5-day operation schedule

Now we can observe a very different outcome. The distribution tale is extremely long and up to 40% of the time the container usage would be in the range of 77-84 and above. The average usage is more or less 65 containers and the peaks vary between 140 and 180 mobiles. Without a doubt, this scenario is unfeasible.

A detailed look into the model points out that the mismatch of schedules is the reason why this is not possible. The storage of containers that need to be consumed during the 2 days that

Making is not producing need to be pre-produced and therefore increasing the storage requirements.

So, in order to consider a 5-day operation, it is required that Packing and Making have synchronized schedules.

## 5.6 Interim Summary

At this point of this study the reader might have noticed the range and depth of changes that Mystery will bring to the plant.

Along Chapter 5 we have identified several upsides and downsides. On the positive side we confirmed a capacity improvement in Making, leaving the door open to a 5-day operation schedule and we have discarded issues of capacity in the material handling system and intermediate storage even though we flagged some risks that will require follow-up. On the negative side we have confirmed the negative cost impact on changeovers with a 40% additional costs in Making and we highlighted the serious risks of a variation in the expected cycle times, particularly with the Pre-weigh issue that needs to be addressed. Finally, it has been proven that a 5-day operation is only possible by synchronizing Making and Packing schedules.

Overall, Chapter 5 together with Chapter 4 have set the foundations for the development of an optimal operations strategy, specially adapted to the new situation.

# 6 Future Operations Strategy

*"Improvement usually means doing something that we have never done before"*

Shigeo Shingo (1909-1990)

Chapter 6 will merge all the information gathered in Chapters 4 and 5 as well as the business targets and will accordingly design a lean-oriented optimal operations strategy that not only exploits Mystery's advantages and offsets its disadvantages but also improves supply chain performance and effectiveness.

## 6.1 Definition of requirements and objectives

As every operations strategy, the main objectives can be reduced to the three following aspects:

1. Reducing operating costs
2. Reduce inventories
3. Increase service level

The most challenging part of it is to find the right balance that maximizes the company's value. However, this work deals with an additional handicap. Mystery has increased the challenge and has put pressure on achieving business targets.

The business targets are:

- Packing average order quantity reduced to 2 MM L (current: 2,7)
- Making average campaign length increased to minimum 4 batches (current: 3,6)
- OEE of the new equipment at 80%
- Offset additional changeover costs of Mystery

Defining minimum order quantities and targeting average order quantities is not an easy thing to achieve. Even more difficult if the targets are opposed, this is, reducing Packing order quantities while increasing Making campaign lengths. The truth is that the company is already struggling to increase Making campaign lengths without even reducing Packing average order quantities.

Hence, the first main objective will be to make it possible to achieve the mentioned targets by improving the production planning and control processes in a way that will allow targeting specific campaign lengths through an optimal demand management and allocation of orders.

In relation to these objectives, it is possible to define further requirements. A summary table has been provided. See Table 20.

| Business requirement | Target | Operations requirement | Justification found in chapter: | Current issue |
|---|---|---|---|---|
| Control and target AOQ | - Packing: 2 MM L<br>- Making: ≥ 4 Batch | - Improve PPC processes<br>- Tailor strategies to different product segments<br>- Hold campaign length range within limits | 6.1<br>4.1<br>4.5 | Unstable production frequencies and quantities |
| Minimum OEE new equipment | 80% | Making AOQ ≥ 5 | 5.2 | Making AOQ = 3,6 |
| Offset increased CO costs | Match current costs | Making AOQ ≥ 5 | 4.3<br>5.4 | Making AOQ=3,6<br>2.000.000 € yearly gap |

Table 20: Requirements for the new operations strategy

It is possible to observe in this table that despite having a target of 4 batch per campaign, the OEE and cost saving objectives require a minimum of 5 batches per campaign in Making. Furthermore, we have seen in previous chapters that Mystery needs to avoid the risk of interruption and to do so it is important to avoid very long campaigns. As opposite as the behaviour seen in Chapter 4.5, the new strategy will need to stabilize the production quantities within certain boundaries. An appropriate range would be a range of 5 – 10 batches per campaign. Campaigns above 10 batches should then be split in two different campaigns.

## 6.2 Conceptualization of the new strategy

Once the requirements have been defined, this section will explain the lean concept behind the new production planning and control strategy.

Essentially, the strategy is an adaptation of the concepts developed by Peter L. King [KING09, KING13] called the Product Wheel suited for high-mix process operations and the most recent similar concept by Josef Packowski [PACK14] called the High-Mix Rhythm Wheels.

Based on the segmentation analysis carried out in Chapter 4.1 the new strategy will be tailored to a specific group of products. In line with the ABC/XYZ analysis, the new strategy puts its focus on the AX, BX and BY product in order to maximize impact at a minimum effort.

The implementation of the proposed operations strategy will require the following key changes in Production Planning and Control processes:

1. Medium- and long-term inventory planning and target setting based on best-available aggregated forecast.

   This means basically that the parametrization of the supply chain parameters will remain based on forecasts.

2. Final production quantities will be triggered by current inventory status and real consumption needs. This means:
   a. A fixed sequence
   b. Variable final quantities (among boundaries)

   At this point we de-couple what is called the Tactical Planning Parametrization from the Operational Planning Execution. This is, thanks to point 1, we have a “pre-configured” system which is partially based on forecasts, but when it comes to execution, the company reacts to customer demand.

3. Last but not least, the successful strategy requires to convert all the selected candidates to Fixed Safety Stock.

   This is important. Dynamic Safety Stocks are continuously relying on forecast and consequently tend to cause excess stock. Plus, they need constant effort to adjust the values. Safety Stocks need to be specifically designed to be adapted to this operations strategy, and the key thing is: demand/supply variability and volatility must be covered with the safety stocks, which is what they are designed for. Covering the variability with our production resources results in the typical example of Forrester’s “Bullwhip Effect”, which ends up passing the amplified variability through the whole supply chain up to the suppliers. Inventory status being below safety stock is not necessarily a problem but a sign of good usage of safety stock.

Fixed sequence – variable production quantity will allow to pre-schedule production way before the time of production and thanks to the thorough analysis there will be a high likelihood that the pre-scheduled product will be actually demanded, independent from the final production quantity, which will be decided only at time of final scheduling. Due to the planning cycles and time fence, the frequency of production will be weekly, every two weeks, monthly and quarterly. On very specific occasions some products will be selected for two times a week.

The concept of sequencing used for this approach has been represented in Figure 46. Similar as today, the production will be sequenced in such a way that it promotes formula campaigns and minimizes changeover losses. Based on the results of Chapter 4, the main target is set to minimize changeovers with washouts, even at the cost of increasing changeover without washouts.

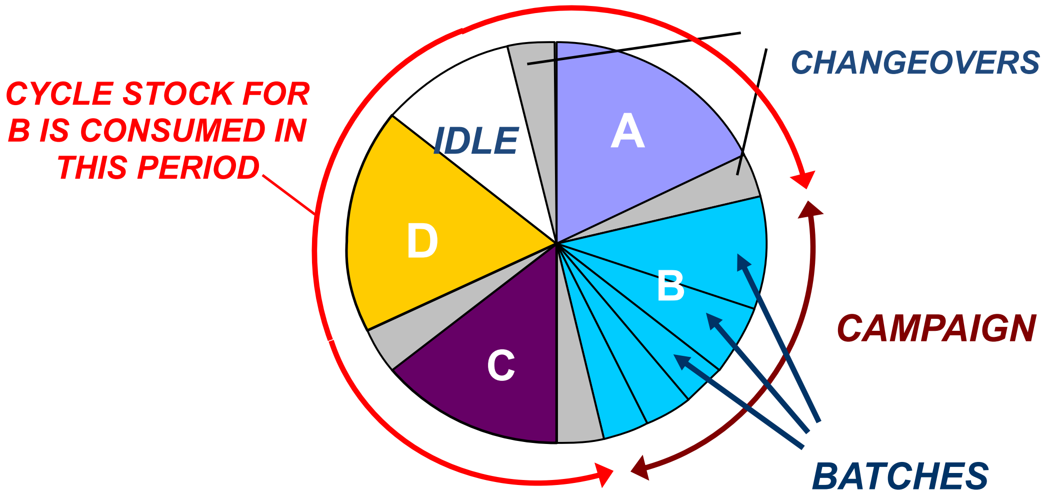



Figure 46: Production sequence “wheel” approach

Consequently, it is not only the plant that will be able to sequence their production, but also this information could be passed to the suppliers in order to improve supplier reliability.

As shown in Figure 47, the manufacturing environment would then change from a forecast-driven Push strategy to a hybrid Push/Pull strategy in a more consumer-driven situation.

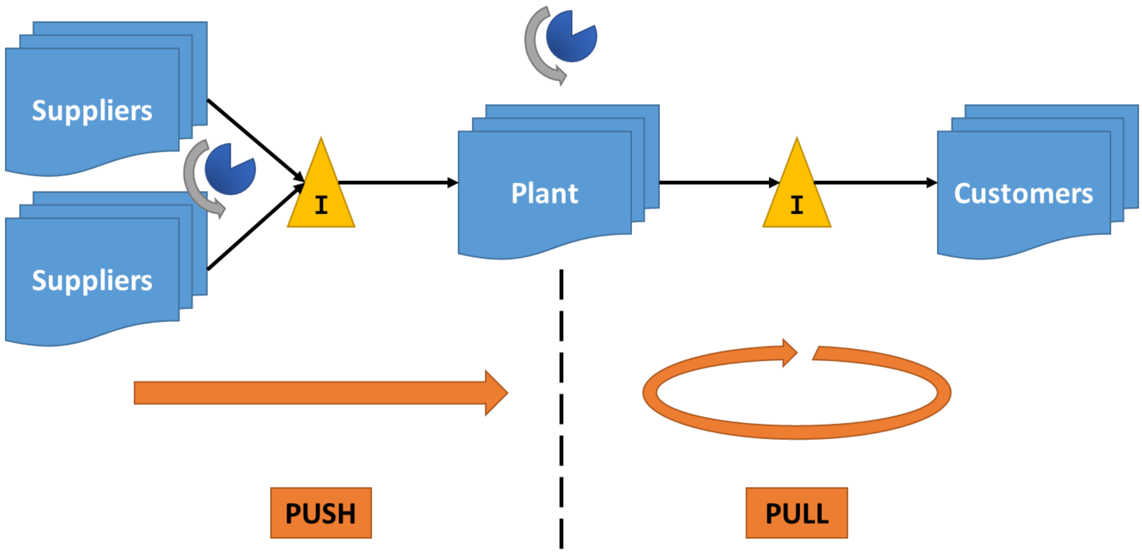



Figure 47: Concept of a hybrid Push/Pull environment for the selected portfolio segment (Consumer-driven)

There is still the rest of the portfolio to be considered (AZ, BY, BZ, CX, CY, CZ) products that will need to be managed the same way as today, but with the advantage of having a pre-defined schedule where these other items can be planned more easily and faster as they represent only a small portion of the total volume. Figure 48 describes how would the push-environment for the rest of the portfolio look like.

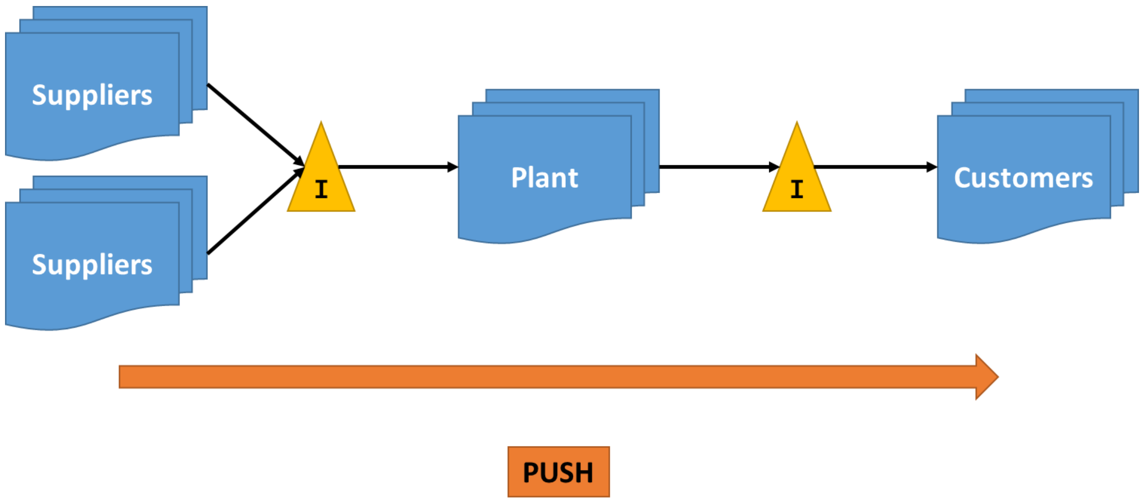



Figure 48: Concept of a Push environment for the non-selected portfolio segment (Produce to Forecast)

## 6.3 Selection criteria of suitable candidates

Perhaps the most critical aspect of this concept is to select the appropriate set of products that qualify for the strategy.

To do so, a specific tool has been developed to standardize the selection process. This tool is specifically adapted to the requirements and restrictions of the plant. The great thing about the selection tool is that it actually allows to target the average order quantities of Making and Packing independently. The tool guarantees that the resulting set of products meet the order quantity targets on a sustained manner.

Inputs are:

- Demand volume
- Demand CoV
- AOQ targets (Making and Packing independently)
- CoV limits
- Shipping Lanes by final product
- Product characteristics (Formula/Packaging requirements)

For example, in the case that we are studying, the need is to reach an average order quantity of 2 MM L in Packing while having a formula average order quantity of 4 Batches. In this case the candidate tool will simultaneously look for every SKU that meet the Packing 2 MM L criteria and test if the corresponding Formula would comprise enough volume of that same SKU or from other SKU's that share the same formula. If both criteria are not met, an SKU that could be valid for a weekly production of 2 MM L in Packing cannot be produced weekly, due to the Making constraint. However, if there are other SKU's of that formula, and they are sequenced in a smart way (by grouping them together) then it would be possible to produce several SKU's with an average order quantity of 2 MM L and a 4 batches at a formula level.

Finally, these are the direct outputs provided by the tool:

- List of Final Products qualified for the strategy
- List of Formulas qualified for the strategy
- Average Order Quantity for each product and formula
- Frequency of production for each product and formula

The tool also leaves some borderline candidates for a second manual review.

The next step consists on finding the right sequence. For that, the tool suggests the possible packaging lines where each product could be produced and lets you decide based on the line utilization and capacity in order to make a balanced pre-schedule.

With all the tool's information, the Production Planning and Control parameters can be properly adjusted.

The result would be a pre-defined schedule comprising 60% to 70% of the volume where planners would only adjust the production quantity or break the sequence in exceptional cases when the demand deviates too much from the agreed boundary. In such cases where the demand exceeds the boundary, the needed volume would be covered by safety stocks.

**Periodic review of the candidates**

Due to the fast-moving industry of the consumer goods, the results are not valid indefinitely. A standard periodic review and re-selection of candidates needs to be carried out with certain frequency. It will be important to determine the frequency. A high frequency would involve too much effort and would not bring major changes but a too low review frequency can result in a bad performance and very frequent sequence breaks.

## 6.4 Case-study: Example of the application of the new operations strategy

In order to prove the concept presented in this work, this section will carry out an actual simulation of the whole process.

**Candidate selection**

With the aforementioned requirements and targets, the tool has provided a candidate list. After reviewing the borderline candidates, the list contains:

- 378 SKU's that qualify for the strategy
- A total of 171 MM L/month would be included (84% of monthly volume)
- 19% of monthly volume would be valid for a weekly production

- 30% of monthly volume would be valid for bi-weekly production
- 22% of the monthly volume would be valid for a monthly production
- 14% of the monthly volume would be valid for a quarterly production

By applying the operations strategy to this set of products we fulfilled all the requirements mentioned in Table 20.

However, the benefits are not limited to the basic requirements. The stability along the supply chain thanks to the parametrization and the consumer-driven operations provide a cash benefit in many cases.

Figures 49 to 52 test this additional stability and cash benefits. To prove it, we picked two different suitable items and compared the reality with a simulation of what would have happened if we had followed the rules of the operations strategy. The actual consumption and production data have been pulled from SAP.

The formulas and assumptions used for the simulation of production and inventory status are presented in Table 21.

| **Assumptions for the inventory and production simulation** |
|---|
| > Would-be Total Plant Stock = Would-be MRP Available Stock (any blocked finished goods) |
| > Would-be Total Plant Stock (t) = Would-be Total Plant Stock (t-1) + Proposed Production Qty (t0) - Total Usage (t0) |
| > Would-be Total Plant Stock(t0) = Total Plant Stock(t0) |
| > Max. 1 production run / agreed cycle (according to frequency) |
| > Max Boundary = RoundUP(135% Avg. MM L/Cycle) |
| > Min Boundary = Max[RoundDOWN(70% Avg. MM/Cycle) ; MOQ] |
| > Proposed Production Qty = Proposed SS + Avg. MM L/Cycle - Would-be Total Stock |
| > Proposed SS = Z(98,5%) * ( SQRT(frequency/30)*St.Dev demand + St.Dev LT * Avg. Demand ) |

Table 21: Assumptions for the inventory and production simulation

During the real execution of the operations strategy, rules such as the max/min boundaries should be adjusted based on performance.

## Results

1. Final product A
    - Formula: Red
    - Production frequency: every two weeks
    - Average production quantity: 2 MM L
    - Min. Boundary: 2 MM L (MOQ)
    - Max. Boundary: 3 MM L

As seen in Figure 49 and 50, the real inventory data shows an average inventory level of 6,6 MM L vs an expected 3,6 MM L if the operations strategy had been applied (45% inventory reduction). Additionally, fixed safety stock was properly used to cover variability and there would have been no stock-outs.

In terms of production stability, Figure 50 indicates a much more stable pattern under the proposed strategy. The strategy would have delivered constant weekly productions in the range of 2-3 MM L while the real production range was 2-6 MM L. Furthermore, even though we observe some weeks without production, with the new strategy the skipped weeks are homogenously spread over time and the inventory could handle the demand without problems. That was not the case in reality, where the predictability as to when was this product going to be produced was extremely uncertain. Clearly, this product missed the forecast during August-September 2015 and as a consequence there was an excess inventory during the following months. Reacting to customer demand through the proposed strategy would have been successful in this example.

2. Final Product B
    - Formula: Blue
    - Production frequency: weekly
    - Average production quantity: 2,1 MM L
    - Min. Boundary: 2 MM L (MOQ)
    - Max. Boundary: 3 MM L

In this case, the safety stock in the reality was better managed than in the previous example. However, if applying the suggested operations strategy, the average inventory would have still been reduced by 19% from 7 MM L to 5,7 MM L. The simulation shows also no stock-outs during the simulated period.

In terms of production stability, the results are even better than in the previous example. Steady weekly production in the range of 2 to 3 MM L with very few skips while in reality there was a production range of 2 to 7 MM L and a very unstable production pattern.

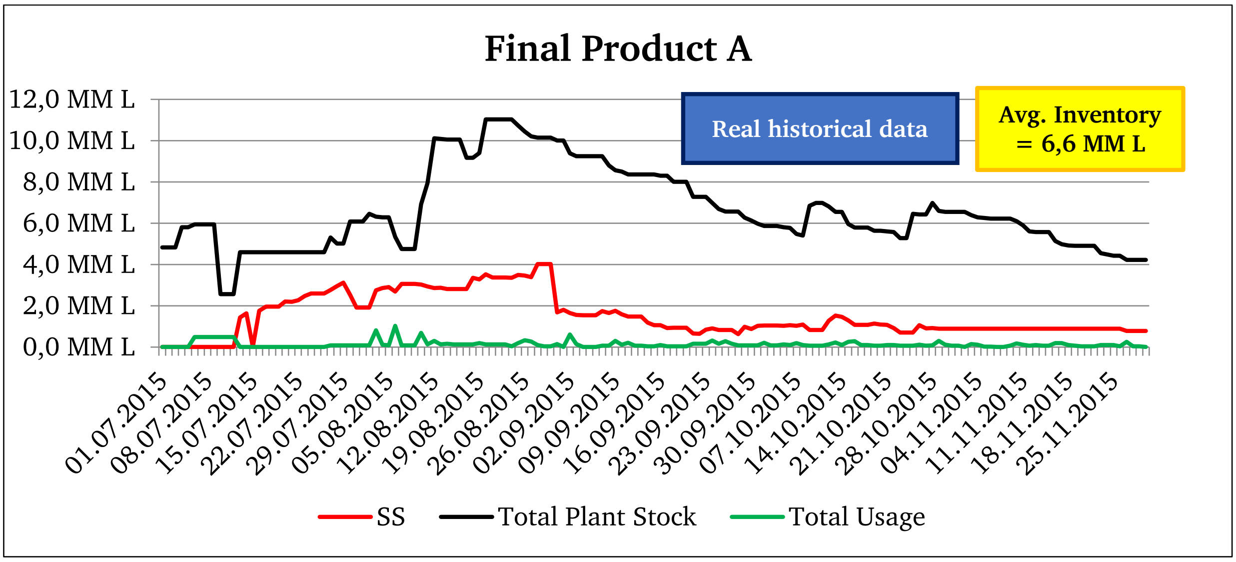
Overall, the simulation has shown very encouraging results.

## 6.5 Further synergies

This proposal of a lean production planning and control strategy has proved to deliver the targets and positive results. In addition, it opens the door to further supply chain optimization such as the involvement of suppliers. The main direct synergies that could be further considered are:

- Suppliers: Fix and stable sequence allow the suppliers to optimize their own production and become more reliable. An agreement to share raw material safety stock for the AX, AY and BX items could further improve the results of both parties.
- Transportation: There is also room for optimizing the transportation costs by promoting full trucks through a shipping-lane oriented sequence.
- Ability to tailor average order quantities for specific segments: One step further by tailoring strategies such as customer segment (e.g. value, region, etc.)

The mentioned synergies entail some interesting opportunities and they should be further analyzed after the full implementation of the operations strategy.



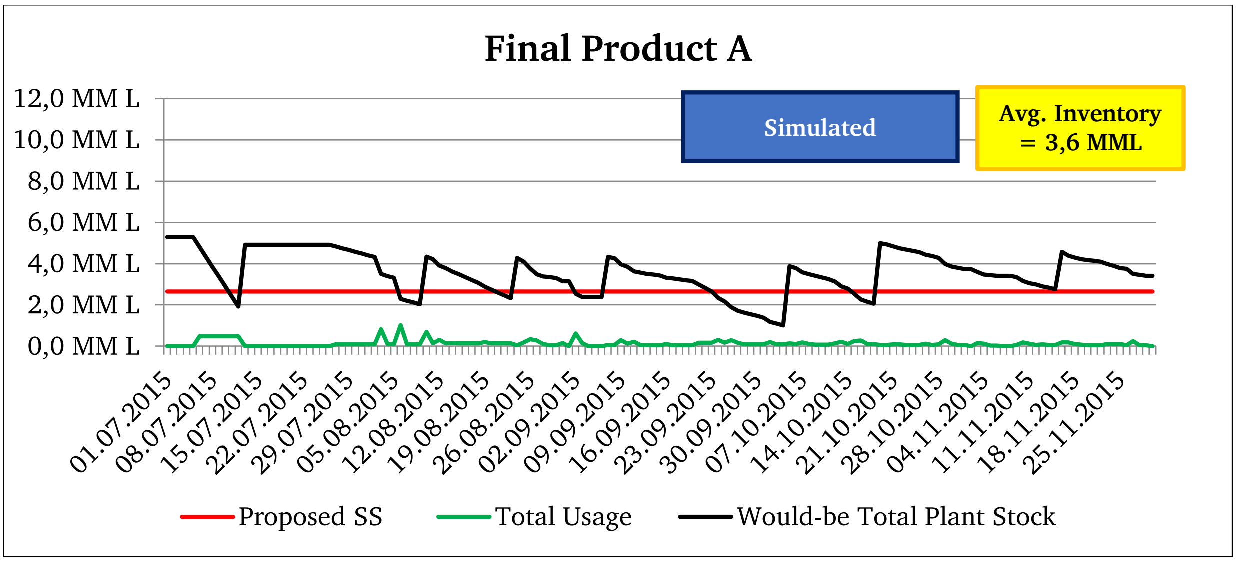




Figure 49: Example 1: Real inventory data vs. Simulated inventory after strategy implementation

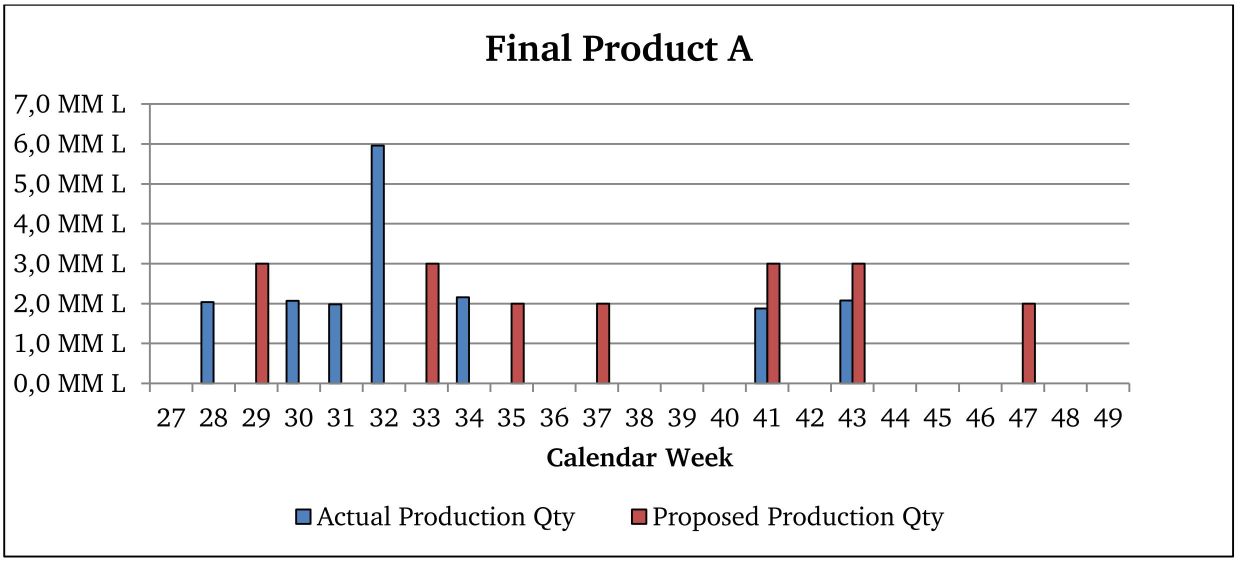
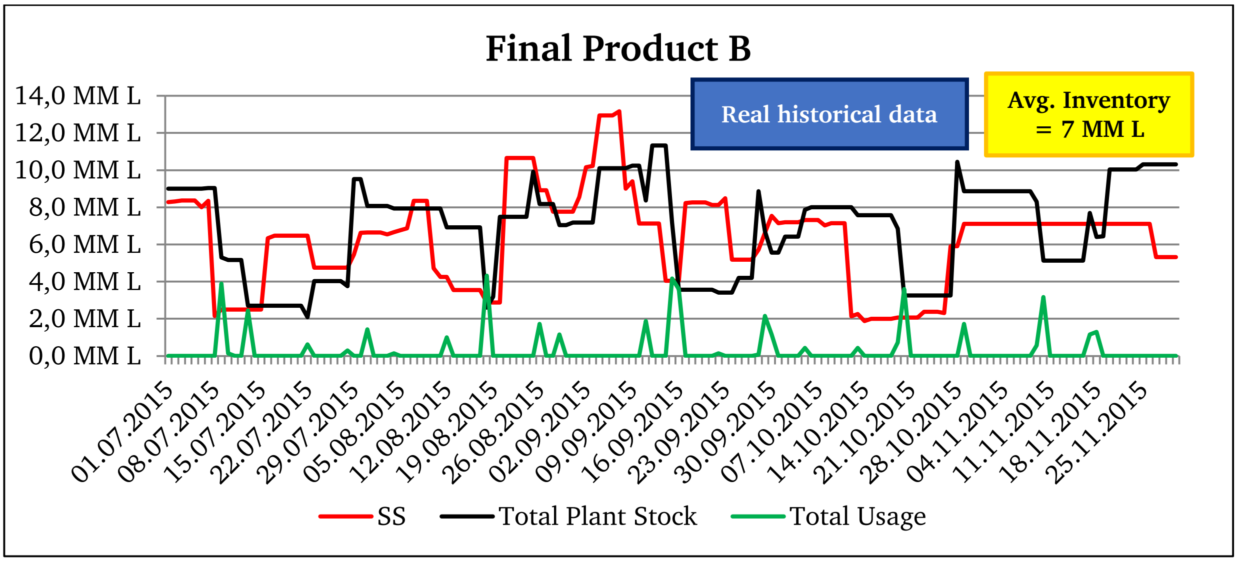



Figure 50: Example 1 – Actual Production Qty vs Simulated Production Qty after strategy implementation



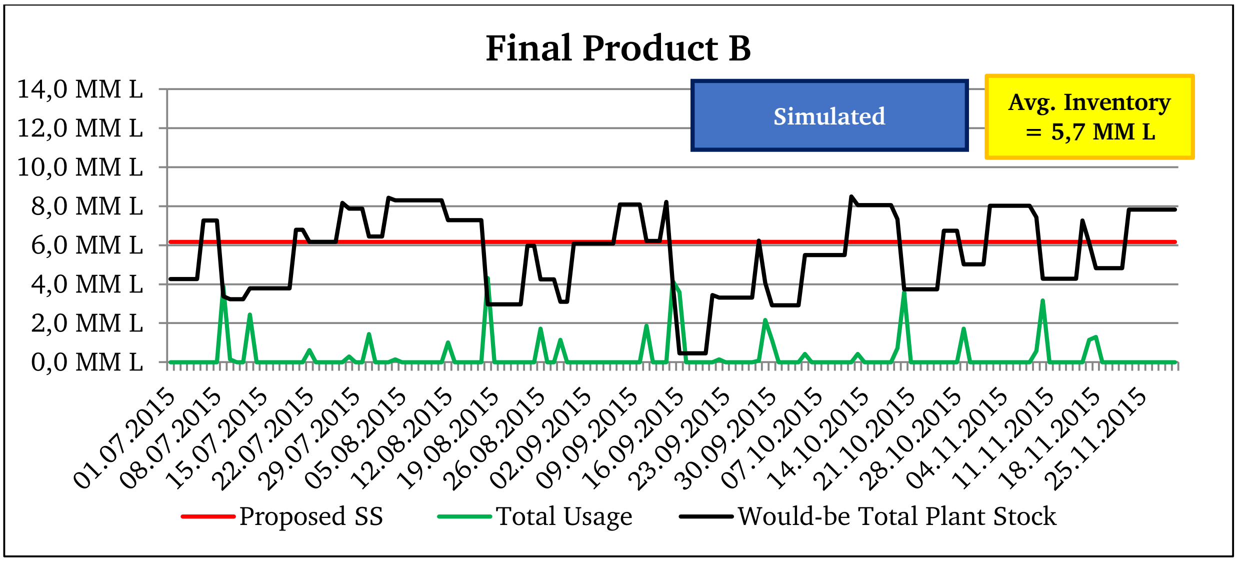




Figure 51: Example 2: Real inventory data vs. Simulated inventory after strategy implementation

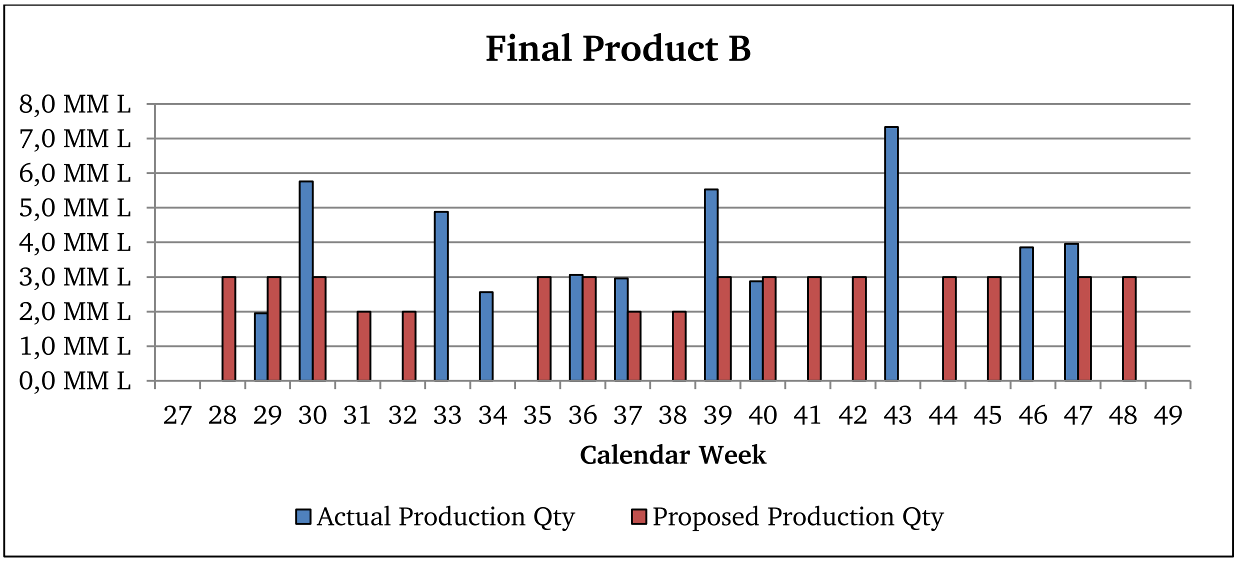



Figure 52: Example 2 – Actual Production Qty vs Simulated Production Qty after strategy implementation

# 7 Summary and Outlook

## 7.1 Summary

This study has completed an extensive analysis focused on different areas:

- Current state analysis (Chapter 4)
  This chapter has presented a portfolio segmentation based on volume and variability, OEE losses in each department, change over losses, packaging complexity and available capacity in each department.
- Future state analysis (Chapter 5)
  The focus in this chapter was to measure the impact of Mystery. Plenty of information has been studied and the results of several models have discarded synchronization issues neither in the material handling system nor in the intermediate storage. Several risks such as the Pre-Weigh issue have been flagged during the analysis. Another important outcome of the chapter has been the identification of the parameter Cleaning new equipment as the bottleneck process in the new manufacturing process. Last but not least, the increased Making capacity that will be expected after Mystery's implementation will enable a 5-day operations schedule on average months.
- Lean production planning and control proposal (Chapter 6)
  A combination of the relevant information of chapters 4 and 5 have been used as the input for the development of a High-mix Rhythm Wheel. This Lean PPC tool entails a fixed production sequence with variable production quantities. The supply chain needs to be parametrized with this approach. One of the most important parameter changes required is the introduction of fixed safety stocks in all the valid candidates.
  All the simulations indicate that the implementation of the suggested approach would bring major benefits to the plant's operations. Among these benefits we find the ability to target independent AOQ in Making and Packing, being able to reduce Packing AOQ while increasing Making AOQ. Also the production quantities and the production frequency seem to be much more stable thanks to the use of fixed sequences. In terms of inventory levels, the suggested strategy has achieved in the 2 examples analysed, a 45% average inventory reduction and a 19% inventory reduction, respectively.

## 7.2 Outlook

The first results are promising and show a high improvement potential. However, all the simulations conducted in this work are highly theoretical (even though all the models have been validated by testing known conditions).

The work has not gone that further to implement the suggested strategy. The reach and scope of the proposal is relative high and require high commitment from various stakeholders in order to move forward.

One thing that is already in place and will serve for the implementation is the standardized candidate selection process.

Nevertheless, there are many things that will be needed:

- KPIs that test performance of the Rhythm Wheel
- Define a review frequency to update the candidate list
- Fine-tuning of some parameters
- Definition of "wheel breakers", a clear standard that helps deciding when to break the strategy rules (e.g. production quantity boundaries)
- SAP integration on the long-term desired (although an execution via excel-based tools is also possible)
- Cultural transformation, which is an important point. (everyone needs to be on board)

Regarding the synergies:

- Door open to big opportunities. Considering them can bring extra benefits.

Regarding other improvement opportunities that came out during the analysis:

- Work with union to find a solution that allows to operate on a 5-day operations when demand is just average (Making and Packing same schedule)
- Improve changeover losses awareness beyond time. Reduce focus on OEE and increase focus on better suited KPI's.

[ABDU06] Abdulmalek, Fawaz A., Rajgopal, Jayant & Needy, Kim LaScola (2006): A Classification Scheme for the Process Industry to Guide the Implementation of Lean. Engineering Management Journal, 18, 15-25.

[ABDU07] Abdulmalek, F. A. & Rajgopal, J. (2007): Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. International Journal of Production Economics, 107, 223-236.

[ABEL12] Abele, Prof. Dr.-Ing. E. (2012): Management industrieller Produktion - Vorlesungsskript Wintersemester 2012/13, PTW - TU Darmstadt.

[AHMA05] Ahmad, Munir, Dhafr, Nasreddin, Benson, Roger & Burgess, Brian (2005): Model for establishing theoretical targets at the shop floor level in specialty chemicals manufacturing organizations. Robotics and Computer-Integrated Manufacturing, 21, 391-400.

[ARLB11] Arlbjorn, J. S., Freytag, P. V. & de Haas, H. (2011): Service supply chain management A survey of lean application in the municipal sector. International Journal of Physical Distribution & Logistics Management, 41, 277-295.

[ASHA96] Ashayeri, J., Teelen, A. & Selen, W. (1996): A production and maintenance planning model for the process industry. International Journal of Production Research, 34, 3311-3326.

[BECK08] Becker, T. (2008): Prozesse in Produktion und Supply Chain optimieren, Springer Berlin Heidelberg.

[BELV05] Belvedere, Valeria & Grando, Alberto (2005): Implementing a pull system in batch-mix process industry through Theory of Constraints: A case-study. Human systems management : HSM, 24, 3-12.

[BERT90] Bertrand, J. W., Wortmann, J. C. & Wijngaard, J. (1990): Production control : a structural and design oriented approach, Amsterdam u.a., Elsevier.

[BHAS15] Bhasin, S. (2015): Lean Management Beyond Manufacturing: A Holistic Approach, Springer International Publishing.

[BICH09] Bicheno, J. & Holweg, M. (2009): The Lean Toolbox: The Essential Guide to Lean Transformation, Production and Inventory Control, Systems and Industrial Engineering (PICSIE) Books.

[BLAC13] Blackstone, John H. (2013): APICS Dictionary, Chicago, IL., APICS.

[BLOM98] Blomer, F. & Gunther, H. O. (1998): Scheduling of a multi-product batch process in the chemical industry. Computers in Industry, 36, 245-259.

[BONA06] Bonavia, T. & Marin, J. A. (2006): An empirical study of lean production in the ceramic tile industry in Spain. International Journal of Operations & Production Management, 26, 505-531.

[BONN99] Bonney, M. C., Zhang, Zongmao, Head, M. A., Tien, C. C. & Barson, R. J. (1999): Are push and pull systems really so different? International Journal of Production Economics, 59, 53-64.

[BRUN14] Brunner, F.J. (2014): Japanische Erfolgskonzepte : KAIZEN, KVP, Lean Production Management, Total Productive Maintenance, Shopfloor Management, Toyota Production System, GD3 - Lean Development, Hanser.

[CRAM01] Crama, Yves, Pochet, Yves & Wera, Yannic (2001): A discussion of production planning approaches in the process industry. Université catholique de Louvain, Center for Operations Research and Econometrics (CORE).

[CUA01] Cua, K. O., McKone, K. E. & Schroeder, R. G. (2001): Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. Journal of Operations Management, 19, 675-694.

[CHIA15] Chiarini, A., Found, P. & Rich, N. (2015): Understanding the Lean Enterprise: Strategies, Methodologies, and Principles for a More Responsive Organization, Springer International Publishing.

[DENN00] Dennis, D. R. & Meredith, J. R. (2000a): An analysis of process industry production and inventory management systems. Journal of Operations Management, 18, 683-699.

[DISH13] Nayak, Disha M., Kumar, Vijaya, Naidu, G. Sreenivasulu & Shankar, Veenaa. (2013): Evaluation Of Oee In A Continuous Process Industry On An Insulation Line In A Cable Manufacturing Unit.

[DONK01] van Donk, Dirk Pieter (2001): Make to stock or make to order: The decoupling point in the food processing industries. International Journal of Production Economics, 69, 297-306.

[ERLA12] Erlach, K. (2012): Value Stream Design: The Way Towards a Lean Factory, Springer Berlin Heidelberg.

[FELD00] Feld, W.M. (2000): Lean Manufacturing: Tools, Techniques, and How to Use Them, CRC Press.

[FERN15] Clotet, Joaquim Fernàndez. (2015): Lean production planning and control in semi-process industries. Norwegian University of Science and Technology.

[FRAN94] Fransoo, J. C. & Rutten, W. G. M. M. (1994): A Typology of Production Control Situations in-Process Industries. International Journal of Operations & Production Management, 14, 47-57.

[FULL01] Fullerton, R. R. & McWatters, C. S. (2001): The production performance benefits from JIT implementation. Journal of Operations Management, 19, 81-96.

[GORE13] Gorecki, Pawel & Pautsch, Peter (2013): Lean Management : Auf den Spuren des Erfolges der Managementphilosophie von Toyota und Co, München, Hanser Verlag.

[GUNA98] Gunasekaran, A. (1998): Agile manufacturing: enablers and an implementation framework. International Journal of Production Research, 36, 1223-1247.

[HODG11] Hodge, George L., Goforth Ross, Kelly, Joines, Jeff A. & Thoney, Kristin (2011): Adapting lean manufacturing principles to the textile industry. Production Planning & Control, 22, 237-247.

[HOEK92] Hoekstra, Sjoerd & Argelo, S. M. (1992): Integral logistic structures : developing customer-oriented goods flow, New York, NY, Industrial Press.

[HOPP04] Hopp, Wallace J. & Spearman, Mark L. (2004): To Pull or Not to Pull: What Is the Question? Manufacturing & Service Operations Management, 6, 133-148.

[JIME12] Jimenez, E., Tejeda, A., Perez, M., Blanco, J. & Martinez, E. (2012): Applicability of lean production with VSM to the Rioja wine sector. International Journal of Production Research, 50, 1890-1904.

[JONS06] Jonsson, P. & Mattsson, S. A. (2006): A longitudinal study of material planning applications in manufacturing companies. International Journal of Operations & Production Management, 26, 971-995.

[KEMP08] Kemppainen, K., Vepsalainen, A. P. J. & Tinnila, M. (2008): Mapping the structural properties of production process and product mix. International Journal of Production Economics, 111, 713-728.

[KING09] King, Peter L. (2009): Lean for the process industries: dealing with complexity, CRC Press.

[KING13] King, Peter L. & King, J.S. (2013): The Product Wheel Handbook: Creating Balanced Flow in High-Mix Process Operations, Taylor & Francis.

[LYON13] Lyons, A. C., Vidamour, K., Jain, R. & Sutherland, M. (2013): Developing an understanding of lean thinking in process industries. Production Planning & Control, 24, 475-494.

[MAHA07] Mahapatra, S. S. & Mohanty, S. R. (2007): Lean Manufacturing in Continuous Process Industry: An Empirical Study. Journal of Scientific and Industrial Research, 66, 19-27.

[MELT05] Melton, T. (2005): The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries. Chemical Engineering Research and Design, 83, 662-673.

[MOND94] Monden, Yasuhiro (1994): Toyota production system : an integrated approach to just-in-time, London u.a., Chapman and Hall.

[MUKH05] Mukhopadhyay, S. K. & Shanker, S. (2005): Kanban implementation at a tyre manufacturing plant: a case study. Production Planning & Control, 16, 488-499.

[NAHM09] Nahmias, Steven (2009): Production and operations analysis, New York, McGraw-Hill/Irwin.

[ŌHNO93] Ōhno, Taiichi (1993): Das Toyota-Produktionssystem, Frankfurt/Main u.a., Campus-Verl.

[OLIV08] Oliveira, C.S. & Pinto, E. B. (2008): Lean Manufacturing Paradigm in the Foundry Industry. Estudos Tecnológicos, 4, 218-230.

[PACC04] Pacciarelli, Dario & Pranzo, Marco (2004): Production scheduling in a steelmaking-continuous casting plant. Computers & Chemical Engineering, 28, 2823-2835.

[PACK14] Packowski, Josef (2014): Lean supply chain planning the new supply chain management paradigm for process industries to master today's VUCA world, Boca Raton, Fla. ˆ[u.a.]‰, CRC Press.

[PANW15] Panwar, A., Nepal, B. P., Jain, R. & Rathore, A. P. S. (2015): On the adoption of lean manufacturing principles in process industries. Production Planning & Control, 26, 564-587.

[PART07] Partovi, F. Y. (2007): An analytical model of process choice in the chemical industry. International Journal of Production Economics, 105, 213-227.

[PETR06] Petrovic, D. & Duenas, Alejandra (2006): A fuzzy logic based production scheduling/rescheduling in the presence of uncertain disruptions. Fuzzy Sets and Systems, 157, 2273-2285.

[PINE12] Pinedo, M.L. (2012): Scheduling: Theory, Algorithms, and Systems, Springer New York.

[POOL11] Pool, Arnout, Wijngaard, Jacob & van der Zee, Durk-Jouke (2011): Lean planning in the semi-process industry, a case study. International Journal of Production Economics, 131, 194-203.

[POWE10] Powell, Daryl, Alfnes, Erlend & Semini, Marco (2010): The Application of Lean Production Control Methods within a Process-Type Industry: The Case of Hydro Automotive Structures. In: VALLESPIR, B. & ALIX, T. (eds.) Advances in Production Management Systems. New Challenges, New Approaches. Springer Berlin Heidelberg.

[PYKE90] Pyke, David F. & Cohen, Morris A. (1990): Push and pull in manufacturing and distribution systems. Journal of Operations Management, 9, 24-43.

[RADN06] Radnor, Z, P, Walley, A, Stephens & Bucci, G (2006): Evaluation of he Lean Approach to Business Management and Its Use in the Public Sector. Scottish Executive.

[SALM07] Salman, Mustafa Ramzi, van der Krogt, Roman, Little, James & Geraghty, John (2007): Applying lean principles to production scheduling.

[SCOT11] Scott, Colin, Lundgren, Henriette & Thompson, Paul (2011): Guide to supply chain management. Berlin ˆ[u.a.]‰: Springer.

[SCHR94] Schragenheim, E., Cox, J. & Ronen, B. (1994): Process Flow Industry - Scheduling and Control Using Theory of Constraints. International Journal of Production Research, 32, 1867-1877.

[SCHU00] Schuster, Edmund W, Allen, Stuart J & D'Itri, Michael P (2000): Capacitated materials requirements planning and its application in the process industries. Journal of Business Logistics, 21, 169-189.

[SHAH03] Shah, Rachna & Ward, Peter T. (2003): Lean manufacturing: context, practice bundles, and performance. Journal of Operations Management, 21, 129-149.

[SHAH05] Shah, N. (2005): Process industry supply chains: Advances and challenges. Computers & Chemical Engineering, 29, 1225-1235.

[SHAM10] Rahman, Shams, Laosirihongthong, Tritos & Sohal, Amrik S. (2010): Impact of lean strategy on operational performance: a study of Thai manufacturing companies. Journal of Manufacturing Technology Management, 21, 839-852.

[SIMO05] Simons, David & Zokaei, Keivan (2005): Application of lean paradigm in red meat processing. British Food Journal, 107, 192-211.

[SOHA94] Sohal, A. S. & Egglestone, A. (1994): Lean Production - Experience among Australian Organizations. International Journal of Operations & Production Management, 14, 35-51.

[SOMA04] Soman, Chetan Anil, van Donk, Dirk Pieter & Gaalman, Gerard (2004): Combined make-to-order and make-to-stock in a food production system. International Journal of Production Economics, 90, 223-235.

[SUGI77] Sugimori, Y., Kusunoki, K., Cho, F. & Uchikawa, S. (1977): Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system. International Journal of Production Research, 15, 553-564.

[TAJ11] Taj, Shahram & Morosan, Cristian (2011): The impact of lean operations on the Chinese manufacturing performance. Journal of Manufacturing Technology Management, 22, 223-240.

[TSIG12] Tsigkas, A. (2012): The Lean Enterprise: From the Mass Economy to the Economy of One, Springer Berlin Heidelberg.

[WERN07] Werner, H. (2007): Supply Chain Management: Grundlagen, Strategien, Instrumente und Controlling, Gabler Verlag.

[WOMA03] Womack, James P. & Jones, Daniel T. (2003): Lean Thinking : banish waste and create wealth in your corporation, London u.a., Simon and Schuster.

[WOMA90] Womack, James P., Jones, Daniel T. & Roos, Daniel (1990): The machine that changed the world, New York, Rawson Ass. u.a.

[ZRIL13] Zrilic, Antonio (2013): Six Steps Inventory Optimization.