Lund University

Master Thesis

Logistics and Supply Chain Management

Towards a Feasible Production Strategy

The Development of a Lead-Time Practice at a Chemical Producer

Author:
Oliver Flinck
Jesper Tempel

Supervisor:
Jan Olhager

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Lunds universitet
Lunds Tekniska Högskola

Preface

This report is the final result of a master thesis conducted at the Department of Industrial Management and Logistics at Lund University. Both authors carried out the thesis as part of their Master of Science in Industrial Engineering and Management, at the Faculty of Engineering at Lund University.

The thesis was carried out from January to August 2016 for a chemical producer, denoted ChemCo, with its base in the northern parts of the US.

The authors wish to express their greatest gratitude to all people involved in the thesis.

An especial acknowledgement is deserved by the following people at ChemCo:

- Johan L. for his tutoring, guidance and sincere involvement
- The entire supply chain for their help with the thesis project and for heartfully taking on the authors during their visit in the US
- The Salts production team for being deeply involved in the project

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- Jan Olhager for his supervision, tutoring and continual support and valuable inputs to the thesis process, project and report
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- Dag Näslund for his input and answers related to action research

Lund, August 2016

JESPER TEMPEL

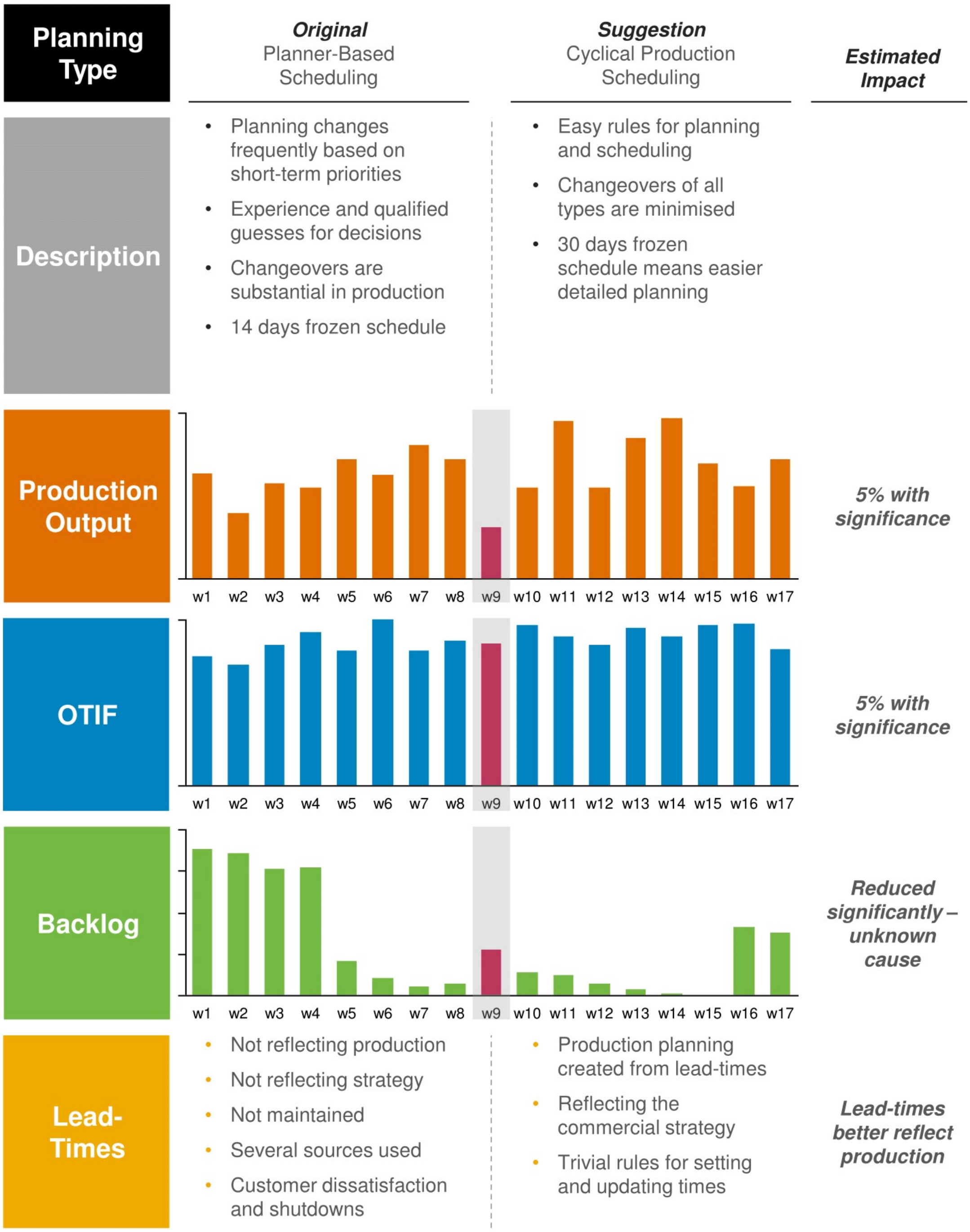
OLIVER FLINCK

Abstract

Title	Towards a Feasible Production Strategy: *The Development of a Lead-Time Practice at a Chemical Producer*
Authors	Jesper Tempel, jesper.tempel@gmail.com Oliver Flinck, o.flinck@gmail.com
Supervisors	Jan Olhager, Faculty of Engineering at Lund University Johan L., ChemCo
Background	ChemCo is a high quality producer in the speciality chemical market, a market characterised by complex production and high variability. With limited system-support and limited data quality, delivery accuracy suffered, and so did production efficiency. ChemCo believed that this was due to poor lead-time performance, why they wished to research the problem. Research on setting lead-times has focused on objective positivist science, where many models are too complicated for practical use. The authors wish to provide ChemCo with a solution of high practical value that has a genuine base in theory, while also being adjusted for their context.
Purpose	This study aims at providing ChemCo with recommendations on feasible modelling of lead-times that is suited for their context.
Methodology	The researchers developed a detailed framework to guide research, based on the concept of an actors view and action research. The problem would be analysed based on the context at ChemCO, and research were to be developed iteratively in cycles.
Conclusion	Through three approaches, the researchers finally recommend a new approach to production planning which would provide simple calculations for lead-times: ChemCo should implement cyclical production scheduling, adjusted for their context. The technique would reduce changeovers and allocate production time based on demand. Impact is expected in many areas, where production output showed to increase, further likely to affect the firm's KPIs.
Keywords	*Lead-times, Production Planning, Campaign Planning, Cyclical Production Scheduling, High Grade Speciality Chemical Market*

Executive Project Summary

An executive summary was created for the project, displayed below in Figure 0.0.1.



Planning Type	***Original*** Planner-Based Scheduling	***Suggestion*** Cyclical Production Scheduling	***Estimated Impact***
Description	• Planning changes frequently based on short-term priorities • Experience and qualified guesses for decisions • Changeovers are substantial in production • 14 days frozen schedule	• Easy rules for planning and scheduling • Changeovers of all types are minimised • 30 days frozen schedule means easier detailed planning	
Production Output			***5% with significance***
OTIF			***5% with significance***
Backlog			***Reduced significantly – unknown cause***
Lead-Times	• Not reflecting production • Not reflecting strategy • Not maintained • Several sources used • Customer dissatisfaction and shutdowns	• Production planning created from lead-times • Reflecting the commercial strategy • Trivial rules for setting and updating times	***Lead-times better reflect production***

Figure 0.0.1: The executive summary from the project carried out at ChemCo.

List of Abbreviations

ABC	ABC-Segmentation: *commonly used segmentation technique*
ANA1	Supply Chain Analyst: *working under the PO*
ANA2	Supply Chain Analyst: *working under the PO*
APO	Advanced Planning & Optimisation: *IT system terminology*
AR	Action Research: *a research design*
ATO	Assemble to Order: *material segmentation based on order-points*
BOM	Bill of Materials: *shows material hierarchy*
CPG	Citation Pearl Growing: *methodology for finding theory*
DEO1	Demand Owner: *working with the forecast*
DEO2	Demand Owner: *working with the forecast*
ERP	Enterprise Resource Planning: *IT system terminology*
GRPT	*See GRT, the abbreviations are synonyms
GRT	*Lab-testing time required: *SAP field for lead-time*
IHP	In-House Production: *production lead-time*
ITE	IT Expert: *responsible for technical aspects in SAP*
LTS	Lead Time Syndrome: *a vicious cycle describing a potential problem of too frequent updates or adjustments to lead-times*
MDO	Master Data Owner: *data owner at the client*
MOQ	Minimum Order Quantity: *a lower restriction for order-sizes*
MPC	Manufacturing Planning & Control: *IT system terminology*
MRP	Material Requirements Planning: *IT system terminology*
MRPC	Material Resource Planning Controller: *IT system terminology*
MTO	Make to Order: *material segmentation based on order-points*
MTS	Make to Stock: *material segmentation based on order-points*
OTIF	On Target, In Full: *KPI commonly used for supply chains*
PDT	*Purchasing Lead-Time: *SAP field for lead-time*
PEN	Production Engineer: *engineer for Salts*
PL:P	Planner Packaging: *plans the packaging for Salts*
PL:S	Planner Salts: *plans the production for Salts*

PO	Project Owner: *client owner of the project*
PS	Project Supervisor: *client supervisor of the project*
QC	Quality Control: *used synonymously with GRT or GRPT*
SAP	SAP SE: *commonly used ERP-system*
SBU	Strategic Business Unit: *structural division at a company*
SIOP	Sales Inventory Operations Planning: *supply chain denotion*
SKU	Stock Keeping Unit: *materials for a company*
SME	Small & Medium-sized Enterprises: *describing company size*
TRLT	Total Replenishment Lead-Time: *total lead-time for a material*
WC1	*Workcentre: *denotion for a workcentre in Salts*
WC2	*Workcentre: *denotion for a workcentre in Salts*
WC3	*Workcentre: *denotion for a workcentre in Salts*
WC4	*Workcentre: *denotion for a workcentre in Salts*
WC5	*Workcentre: *denotion for a workcentre in Salts*
WFI	*Water Classification: *denotes high-quality water used in production*

∗ *explains the abbreviation but does not write it out.*

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Chapter 1

Introduction

This chapter will introduce the thesis subject; the organisation is presented, the initial problem is described, and a purpose and research questions are formulated.

1.1 Notes on Confidentiality

ChemCo is used as a denotion for the real company studied. Due to the confidential nature of ChemCo's business and structure, all products, categories and numbers are anonymised in this report; graphs on performance do not contain Y-axes, while calculations presented are multiplied by a random factor.

1.2 Background

Due to the global nature of today's organisational relationships, widespread emphasis on supply chain effectiveness and efficiency, and an integrated view of suppliers, a good supply chain is both necessary and a potential source of competitive advantage - it is imperative companies to have a well functioning supply chain (Mentzer et al., 2001).

ChemCo, henceforth also *The Company*, is used as the name for a company manufacturing and selling chemicals for an international market. Products are high grade quality materials and chemicals, with typical customers in the high tech, pharmaceutical, laboratory, and academic industries.

ChemCo was recently purchased by a private equity firm and had their name changed, although the company has roots stretching back over 100 years. Since the forming in the early 1900s, the company has expanded its operations around the globe with sites in several continents (ChemCo, 2016).

ChemCo is working in a *Business to Business (B2B)* environment. To stay competitive, it is imperative that the company can compete both with price, and supply chain efficiency and effectiveness. Customers need accurate delivery information and reasonable lead-times in order to plan their business activities - including logistics, production and sales. From the two American plants, ChemCo is supplying approximately 20 000 *Stock Keeping Units (SKUs)* to hundreds of customers. The high amount of SKUs requires effective and efficient production planning to supply customer demand according to requested standards (Mentzer et al., 2001).

1.3 Problem Introduction

ChemCo describes their own supply chain, and management thereof, to show potential in moving towards best-practices. Lot-sizes and production frequency has historically been set arbitrarily or according to experience by production planners. Partly, this is the result of limited ERP-systems usage, with much functionality missing or not maintained. Thereby, even efficient and correct use of these systems would create ineffective planning as a result of outdated data, poor quality, or a combination of the two. Such an approach to planning leads to suboptimal operations, showing in backlog, overstocked inventory, and poor OTIF-performance - the firm's KPIs.

A critical issue is comprised by the (lack of) quality of data. Much data is outdated; some of it not updated since, or before, the SAP implementation in 2012. This lead to different functions of the company keeping internal records of historic performance, often without efforts to maintain SAP data, or telling other functions about their procedure(s). One empirical example during the early days of the study showcased this: customer service and sales described how lead-times used when talking to customers could be disparate from the ones used by production planning and purchasing. Data problems has further implications in how deducible systems load impeachable data, thereby not functioning as wished.

Without a clear policy for analysing and setting lead-times, and without ERP-system support, production planning relies heavily on tacit knowledge, experience based estimates, and qualified guesses. Methodology is not standardised and different planners have developed different methods of tackling their problems. Meanwhile, production efficiency is highly correlated with planning practices.

Increased *Production Planning Performance*, as illustrated above, would affect all parts of the company, including inbound logistics, production, outbound logistics, sales, marketing and customer service - ultimately most parts of ChemCo's supply chain. Increased delivery accuracy would benefit both customer relations and customer operations; upon the start of this study, customer shutdowns occurred weekly.

ChemCo themselves believes that lead-times is the cause for many of these problems, as they directly influence the internal performance measures, but furthermore are the key input data for every SKU in the system. Thereby, the thesis project had its foundation in many problems, where ChemCo believed the situation to be well suited for research.

1.4 Purpose

This study aims at providing ChemCo with recommendations on feasible modelling of lead-times that is suited for their context.

Ultimately, the study should present a case on how a technique can be developed for updating lead-times, how such a technique can work feasibly, and whether ChemCo can expect a performance increase from using it.

1.5 Research Questions

Research questions defining the problem, as identified given a chosen methodology approach, are presented below:

RQ1: How should lead-times be calculated at ChemCo *Salts* production?

RQ2: What technique should ChemCo use to incorporate such calculations?

RQ3: What impact could ChemCo expect from the developed technique?

The reasoning behind each question is elaborated on in the methodology chapter.

1.6 Goal of the Study

The goal of the study is to provide ChemCo with recommendations that will answer the research questions defined above:

1. Suggest a technique for updating lead-times for the *Salts* product category that works in ChemCo's industry landscape and organisation, *and*
2. Implement this technique for at least one production line within *Salts*, *and*
3. Analyse the expected supply chain performance from using the technique

1.7 Focus and Delimitation

The project has a limited time frame comprising analysis, implementation and report writing. ChemCo wants to launch a lead project to analyse impact before implementing any suggestions in other potential product categories. Due to this time limitation, notable delimitation is required to ensure completion within the time frame.

1.7.1 Geographical Coverage

ChemCo is current on several markets worldwide, with the US-branch including only two plants. To enable concrete recommendations, this study will focus on the American branch of ChemCo, including the production in their two American plants and headquarters in the northern US.

1.7.2 Product Categories

In order to deliver precise recommendations and analysis, the project will focus on addressing the problems for one of ChemCo's product groups: *Salts*. Methodology could later be leveraged to other products, given adequate processes.

1.8 Target Group

The primary targets for this thesis are managers within the supply chain management team at ChemCo. The group is familiar with the area of supply chain management - allowing feasible use of certain methodology and modelling. Moreover, the group has certain knowledge of chemical production, which facilitates actual problem solving.

In addition, this study is targeted towards operations management academia, where the authors hope that the study can contribute to knowledge development. The study was conducted with the Department of Industrial Management and Logistics at Lund

University, why the department in itself and students conducting their theses for the department are further targeted.

With the target group in mind, the authors decided not to explain the most fundamental supply chain and academic concepts in this report. It should be noted that the supervisor at ChemCo, who is also the director of the supply chain management team, has conducted a PhD within Industrial Management and Logistics. Adding to that, the other manager involved from ChemCo has worked in close proximity with academia for several years, why such an approach was seen feasible.

1.9 Contribution to Knowledge Development

This project aims to theoretically contribute to knowledge development by analysing an empiric example concerning supply chain management focused on production and planning. The project can hopefully provide insights regarding:

- Theoretical limitations
- Where gaps between theory and practice are rife
- The degree of applicability for well-established theory
- How theory can be adjusted to create a feasible solution fit for continuous use in a professional environment

As described by Voss et al. (2002), empirical examples are needed to cope with “growing frequency and magnitude of changes in technology and managerial methods” (Voss et al., 2002, p. 195). The same authors further emphasise the need to validate such research with practitioners.

Chapter 2

Methodology

2.1 Methodology Approach

> "... what we know today will probably be known better, or rather, differently, tomorrow" (Arbnor and Bjerke, 2009, p. 5)

Methodology for a project must take its goals and considerations into account (Holme and Solvang, 1997). It must fit both with the problem at hand, and presumptions held by researchers; doing so, it acts as "guiding principles for the creation of knowledge" (Arbnor and Bjerke, 2009, p. 9). This section describes the general approach for methodology, aiming at aligning the view of the researchers with the research to be conducted.

2.1.1 Views as Part of Methodology

Arbnor and Bjerke (2009) in their book *Methodology for Creating Business Knowledge* present a view of methodology different from one used by other scientists. Traditionally, many scientists believed that "suitable methods is determined by the problem at hand" (Arbnor and Bjerke, 2009, p. 10); meaning, that given a set problem, there is one right way to develop knowledge. Conversely, Arbnor and Bjerke (2009) describe that "observations, collections of data and results are determined to a large extent by the view chosen" (Arbnor and Bjerke, 2009, p. 7). It is said that the best view cannot be "empirically or logically" (Arbnor and Bjerke, 2009, p. 8) determined. Importantly, this means that methodology should be designed from the researchers' view, as otherwise, "they may even counteract their own purposes" (Arbnor and Bjerke, 2009, p. 14).

Importantly, these views, also called presumptions, help create knowledge rather than disrupt the process of doing so. However, presumptions change over time, where perception tends to develop incrementally; this meaning that a view can develop over time, wich helps creating knowledge (Arbnor and Bjerke, 2009). Closely related, perspectives are important for such knowledge creation: "To be able to look at something from several different perspectives, or to dare, which often go together, always gives the creative mind suggestions for new ideas" (Arbnor and Bjerke, 2009, p. 14).

Problems are affected by the researchers' view: "Problems are never given. They must at least be perceived by others and/or by the creator of knowledge in order to be of interest as methodological objects." (Arbnor and Bjerke, 2009, p. 15).

Ultimately, this means that for a problem to be formulated, a view has to be chosen - including related philosophical assumptions (Arbnor and Bjerke, 2009).

2.1.2 Different Approaches to Methodology

Arbnor and Bjerke (2009) in their work define three views impacting not only the choice of methodology, but also the problems at hand. These are presented in the section following, where-after the authors argue for their choice of view in relation to the company situation at hand in the following subsection.

The Analytical View

Arbnor and Bjerke (2009) describe the analytical view as one not interested in philosophy. Assumptions are made about the reality, which is filled with facts, and is moreover *summative* - meaning, a problem can be decomposed into parts describing such a reality. Thereby, there exists one objective reality, why the analytical view seeks to find clear theories, usually by testing hypotheses. In practice, research is often carried out with statistics in order to find patterns or regularities (Arbnor and Bjerke, 2009; Gammelgaard, 2004).

The Systems View

The systems view also looks at the reality as fact-filled. In contrast to the analytical view, it does not view the world as summative, meaning that problems cannot be split into independent parts. Thereby, studies are concerned with different wholes, and not isolated problems. The goal is to create a better system by analysing the interconnection between parts (Arbnor and Bjerke, 2009). To do so, researchers should be close to the system at hand: "In fact, the researcher should influence the object, as the primary purpose of systems research is to improve systems in practice" (Gammelgaard, 2004, p. 481). However, researchers should not be part of the systems, but instead should work from the outside (Arbnor and Bjerke, 2009).

The systems view looks at problems in their context, why consequently results are somewhat specific to a study (Arbnor and Bjerke, 2009; Gammelgaard, 2004).

The Actors View

The actors view is philosophically split from the others, where reality is seen as a social construct. Thereby, the reality is dependent on the actors involved (Arbnor and Bjerke, 2009; Gammelgaard, 2004): "Reality is not independent of us, but consists of an interaction between our own experiences and the collected structure of experiences that we have over time created together with others" (Arbnor and Bjerke, 2009, p. 29).

As a result, researchers are encouraged to "construct the future from within, the researcher[s] being part of such research reality" (Gammelgaard, 2004, p. 481). Arbnor and Bjerke (2009) explain how dialogue thereby becomes a key element for conducting research. Furthermore, the authors emphasise how, due to the character of research, qualitative research is used as the intentionality of human being is prohibiting the use of traditional and externally-focused cause-and-effect methodology.

2.1.3 An Actors View for the Thesis Subject

To understand a choice of view, the problem as explained by ChemCo is revisited before any subjective reasoning is carried out based on the view chosen, as suggested by Arbnor and Bjerke (2009). ChemCo explained that problems existed in the area of production planning performance, where lead-times was a key problem. Ultimately, their wish was to come up with a method to plan one of their categories going forward.

Scientifically, the problem could be split into two different sub-categories: (1) coming up with a method that could improve performance, but (2) doing so in a way that ChemCo can maintain and understand. *Hence*, the thesis should not necessarily focus on optimality, although solutions needed be built on rigorous theory analysis as suggested by Arbnor and Bjerke (2009), but needed include certain compromising in order to create a method suitable for ChemCo, supported by (Westbrook, 1995).

Given this background of the study, and the interest of the organisation and researchers combined, the actors view was chosen to carry out research. Ultimately, the thesis aim is to provide recommendations for ChemCo, based on their reality. The result should then be analysed and generalised given the theoretical framework (Arbnor and Bjerke, 2009; Gammelgaard, 2004).

Precluding the Analytical View

As for the analytical view, the authors' understanding was that solutions needed were dependant on the context, as a solution was required *specifically* for ChemCo. The authors also believed that hte problem should be analysed in in close intimacy, as opposed to objectively. In addition, researchers describe how the practice of operations management require empirical research from working with companies (Coughlan and Coghlan, 2002; Flynn, 1990; McCutcheon and Meredith, 1993; Reason, 1999; Westbrook, 1995) - there is no one universal truth.

Precluding the Systems View

Concerning the remaining two views, the research did influence the system due to the timing dimension of the report: solving a problem which was current, not past. This means that the solution was developed not retrospectively, but by influencing the system and using knowledge of actors at ChemCo to create a sustainable solution. Differentiating between the two approaches is mainly one key factor: a solution fit for ChemCo is a highly subjective criteria, which cannot be objectively measured. This meaning, that a suitable method for ChemCo is not an objective reality, but rather based on social constructs, capabilities and understanding. This argumentation related highly to the sub-category (2) presented above.

However, such a method cannot be developed without any attachment to theory, why the calculation of lead-times must not be arbitrary. This subset to the major problem as described to ChemCo, is a more generalisable one, focusing on system performance. Ultimately, such a subset can be measured in more objective ways, where output can be benchmarked as described inter alia by (Westbrook, 1995), and agreed upon over social contexts. This part highly related to the sub-category (1) as presented above.

Choosing the Actors View

Ultimately, the actors approach was seen to be best suitable for this research. Although it is obvious that such research is highly contextual, and consequently will develop contextual output (see exampli gratia Arbnor and Bjerke (2009)), the authors hoped to develop theory that could be used as input also in other context. Ultimately, generalisability could be gained not only from rigorous theoretical studies, but also from developing a method in close proximity to industrial professionals. Finally, the authors hoped to use the approach to its potential as described in literature: “the actors approach has the potential to bring research and practice closer together for the benefit of both” (Gammelgaard, 2004, p. 488).

2.1.4 Refining the Problem at Hand

Whereafter a research approach, or view, was chosen, the problem could be revisited and further defined (Arbnor and Bjerke, 2009). To do so, the authors decided the revisit key elements of the actors view:

1. Research is often not linear, but rather ”back-and-forth”
2. Theory of many types and views should be incorporated in reserach
3. Reality is seen as a social construction
4. The scientific ideal advocates an approach where researchers actively interact and drive change

As synthesised from Arbnor and Bjerke (2009) and Gammelgaard (2004).

Knowing this, and knowing that ChemCo believed lead-times to be a key problem for their performance, research questions could be developed, as described below.

Calculating Lead-times

The authors of this report ultimately believed that ”theory of many types” should be used to identify methodology and key concepts for creating lead-times. However, an objective reality was not sought for, but rather a reality as defined by the social constructs at ChemCo. This lead to the first research question:

RQ1 How should lead-times be calculated at ChemCo *Salts* production?

Developing a Methodology

Not only should lead-times be calculated, but ChemCo described the need for a technique which can be used in their context. Such a technique needed have its base in the organisational context of ChemCo, leading to the second research question:

RQ2 What technique should ChemCo use to incorporate such calculations?

Assessing the Methodology in the Actor’s Reality

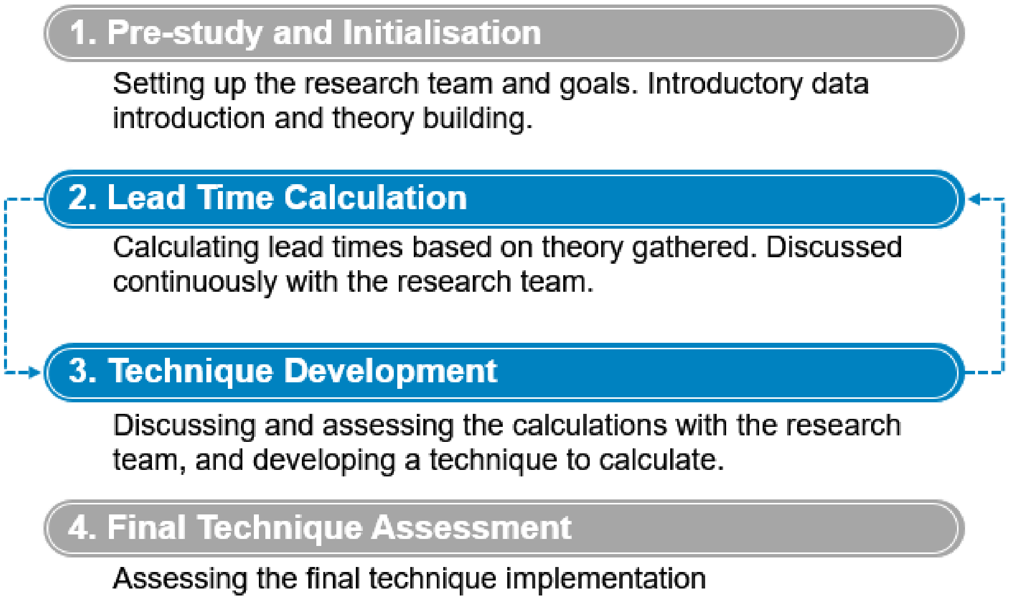
Finally, the technique developed should also be evaluated, where it should not only objectively make sense, but also in the context at ChemCo. Thereby, the assessment of the technique composes the third research question:

RQ3 What impact could ChemCo expect from the developed technique?

2.1.5 The Foundation for Methodology

> "You talk, listen, notice, question, observe and, on the whole, act as you do in everyday life – but with a disciplined reflective attitude" (Arbnor and Bjerke, 2009, p. 29)

Given the three research question *RQ1-3* as defined above, a few key notes could be stated. Firstly, to decide on a technique to calculate lead-times, the researchers realised that they had to work in close proximity to the organisation. Otherwise, the feasibility aspect of the developed technique would be ignored. Moreover, such an approach would, per definition, advocate a "back-and-forth" approach to both research and methodology. With this in mind, the researchers hypothesised a holistic approach to methodology of the project, as presented below in Figure 2.1.1.



1. Pre-study and Initialisation

Setting up the research team and goals. Introductory data introduction and theory building.

2. Lead Time Calculation

Calculating lead times based on theory gathered. Discussed continuously with the research team.

3. Technique Development

Discussing and assessing the calculations with the research team, and developing a technique to calculate.

4. Final Technique Assessment

Assessing the final technique implementation

Figure 2.1.1: Holistic methodology schedule based on the chosen approach: actors view.

Notable is how the two steps in the middle are iterative, working with the organisation, whereas the pre-study and final assessment is one-time occurrences. For an in-detail framework developed, please refer to the next section.

2.1.6 The Study Aims at Extending Theory

Flynn (1990) describes how any research must decide on whether to (1) build or (2) verify theory. Such a decision should be carried out before a research design is chosen (Ibidem). The two choices are presented below:

Theory Building Aims at generating new theory based on some assumptions, frameworks, a perceived problem or tentative hypotheses (Flynn, 1990). Tasks include identifying variables, linkages and explanations (Voss et al., 2002).

Theory Verification Instead focuses on setting up hypotheses and testing them, based on previous theory generation (Flynn, 1990). The choice can be used to predict future outcomes, and is often carried out as experiments, case research or samples (Voss et al., 2002).

In addition to the two methods, Voss et al. (2002) based on Handfield and Melnyk (1998) add one additional choice:

Theory Extension Aims at structure theories based on observation. It discusses where theory is applicable, and as a result, experiments or case studies are often used (Voss et al., 2002).

Given the three choices presented above, the authors found the nature of the study to best fit with (3) theory extension. This meaning, that the study was founded on rigorous theory, and aimed at extending available theory to fit in the case of ChemCo. Thereby, theory applicability could well describe the study, although certain theory was generated to fit the social context, which emphasises the *extension*-part of the concept.

Meredith (1998) explains how interpretive methods indeed are best for generating or extending theory, which concurs with the reasoning above. Similarly, Eden and Huxham (1996) argue that settings where the researchers are working with an organisation are likely to generate new insights, why (2) theory verification is the least applicable of the three choices. Such arguments could be used to further explain how the focus requires some theory generation, as explained above.

2.2 Research Design

> "theory cannot be understood without empirical observation and vice versa"
> (Dubois and Gadde, 2002, p. 555)

An approach to methodology is not enough to conduct research. In addition, research methodology should be designed. Thereafter, data collection should be thought trough, as suggested by Flynn (1990). In this section, the authors present the design choice.

2.2.1 An Introduction to Empirical Research

Authors in the operations management domain describe how the requirement for empirical research has gained exposure over time. McCutcheon and Meredith (1993) describe how there have been several calls for empirical research. Another author describes how "All types of empirical research are needed" (Flynn, 1990, p. 269), and explains that "Tying operations management theory in with practice has been called for over a long period of time" (Flynn, 1990, p. 250).

Limitations of Traditional Research

Reasons behind the increasing demand are many. Eden and Huxham (1996) describe how certain research is over-theoretical, and how certain disciplines require "researchers to be directly involved in 'real world' situations" (Eden and Huxham, 1996, p. 76).

One author explains how traditional research has been questioned as for the "wider relevance to most operations managers" (Westbrook, 1995, p. 6), where several important concepts such as *Just-in-Time* and *Benchmarking* has been developed by practitioners, rather than academics (Westbrook, 1995; Voss et al., 2002). The same authors explain that for practicality, "the aim will usually be to comprise rather than optimize" (Westbrook, 1995, p. 7). Another author develops the questioning of traditional approaches even further: "The trouble with this kind of way of doing research is that there is often limited connection between the researcher's thinking and the concerns and experiences of the people who are actually involved" (Reason, 1999, p. 4). Westbrook (1995) explains that the traditional approach, the *reductionist belief* that problems can be decomposed, "cannot be held simultaneously with a view of operations management as essentially an integrated set of activities taking place in a dynamic social setting" (Westbrook, 1995, p. 11).

In fact, Westbrook (1995) explains how the domain has experienced a "crisis of identity" each time methodology has been revisited. This could explain why the process of conducting empirical research has not often been addressed, as explained by (Kotzab et al., 2005). The same authors explain that this has lead to methods, not included among established ones, being used.

Additional Advantages with Empirical Methodologies

Empirical research has a major advantage in its close proximity to actual practitioners (Eden and Huxham, 1996; Voss et al., 2002; Westbrook, 1995). Moreover, several authors argue that theory and empirical research should go together (Meredith, 1998; McCutcheon and Meredith, 1993; Voss et al., 2002), as suggested by the introductory quote by Dubois and Gadde (2002) starting this chapter. Theory is needed to make sense of empirical data, whereas empirical data helps both develop and show applicability of theory (Voss et al., 2002; Meredith, 1998). Meredith (1998) explains how direct observation allows for the inclusion of contexts, but also for a temporal view: studying phenomenon as they unfold. In addition, Flynn (1990) explains how research conducted in its natural setting also increases external validity, to be revisited later in the methodology.

Ending the introduction on empirical research, the authors believe in the importance of empiric research to actually foster action, well described by Reason (1999, p. 4): "We believe that the outcome of good research is not just books and academic papers, but is also the creative action of people to address matters that are important to them".

2.2.2 Action Research to Drive Change at ChemCo

> "Intervention is the action science analogue of experimentation. When clients involve themselves in change experiments, they engage in non-trivial learning, and they think and reflect seriously on what they are doing." (Dooms et al., 2013 in Eden and Huxham, 1996, p. 17)

The research design chosen for this thesis was *Action Research (AR)*, which counteracts several of the disadvantages mentioned with traditional research above, but also distinguishes itself from other empirical methods, such as *Case Studies*, explained later in this section. Action research focuses on creating results that are of practical value to managers and their organisations (Eden and Huxham, 1996; Reason, 1999; Westbrook, 1995). In addition, research is carried out concerning problems that are of genuine interest to not only managers, but for the organisation (Eden and Huxham, 1996; Westbrook, 1995). Thereby, "the relevance of action research is usually guaranteed" (Westbrook, 1995, p. 18).

General Definition

Coughlan and Coghlan (2002) in their paper "Action research for operations management" define action research as based on 13 previous academic works ranging from 1972 to 2001. Their definition consists of four criteria describing AR:

1. Research in Action AR takes action rather than conducts researcha bout action. The approach evolves during a study, in close proximity to practitioners. In reality, *problems are studied in a scientific way, with the people who experience these problems first hand* (Coughlan and Coghlan, 2002).

2. Participative In comparison to more traditional studies, *participants are not seen as research objects, but are instead participating in cyclical research and development* of the study (Coughlan and Coghlan, 2002; Reason, 1999).

3. Concurrent with Action During AR, *action is continuously taken and evaluated* - it "make[s] that action more effective while simultaneously building up a body of scientific knowledge" (Coughlan and Coghlan, 2002, p. 223).

4. Sequence of Events and an Approach to Problem Solving AR is used as an approach to problem solving, it is however also the actual process carried out: *researchers take part in the change with participants from the organisation.* Consequently, the research aims at creating both learning, theory and solutions - which focus is more vast than that of just the immediate problem (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Westbrook, 1995).

Even with this definition, the reader should know that AR is a broad term used for several types of action-oriented research. Hence, there exists a variety in research conducted with the design. Behind this genericity, lies the fact that AR does *produce both action and research*, as explained by Coughlan and Coghlan (2002).

Characteristics

Major characteristics of AR can be described based on Gummesson (2000) as refered to in inter alia Coughlan and Coghlan (2002). Such a synthesisation is presented below:

1. AR takes action rather than just observing: it is fundamentally about change
2. AR involves two goals: contributing to science and solving a problem
3. AR requires understanding the corporate environment and dynamics
4. AR is interactive: co-operation and adjustments are needed
5. AR should preferably be conducted in real time
6. AR can include different types of data collection tools
7. AR requires its own quality criteria, as positivist measures may not apply

The seven characteristics presented above are the main ones with applicability for this problem, and are expressed by the authors based on the source.

When to Conduct Action Research

Coughlan and Coghlan (2002) refer to clear recommendations on when to conduct action research:

- Describing a series of actions over time in an organisation
- Understanding why action can change or improve some aspects of a system
- Understanding the process of change and learning from it

A practical example of when AR is suitable is presented: “In one case, that of a bank, the project was a practical operational issue – there was a recurring problem which management wanted researched and resolved” (Coughlan and Coghlan, 2002, p. 229).

Requirements

Below, important requirements when working with AR are presented.

To Conduct Action Research Coughlan and Coghlan (2002) explain that in order to conduct successful AR, a real problem has to be found that is of interest both for research and for an organisation. Moreover, adequate resources must be available to conduct actions needed to solve that problem. Furthermore, the importance of AR must be established within the organisation, and the researchers must be welcome to work with the organisation. In order to do so, roles and responsibilities must be defined, where recognising different stakeholders becomes key. Often, the researchers establish a *Project Steering Group*, which aims at (1) planning, implementing and evaluating, as well as (2) building knowledge of the organisation (Coughlan and Coghlan, 2002). The authors decided to follow such a recommendation, and established a group that is presented later in the methodology.

Working With Action Research Eden and Huxham (1996) present several contentions in their work, which are synthesised below:

1. AR must have some implications
2. AR needs to be related to theory
3. The process of theory building will be incremental; theory generated is emergent
4. Researchers need to be clear what consumers should take from theory generated
5. Method and orderliness is required - the exploration should be replicable
6. Triangulation should be used to facilitate the development of theory

Further contentions are presented that have already been touched upon in this section. The contentions are expressed by the authors based on the source.

Main Advantages

Advantages for AR have been mentioned in close proximity to the organisation at hand, and the ability to allow for learning that other methods do not provide. Moreover, the research aims at providing results of direct interest to managers, by working with a problem of genuine interest to them. Closely related, involvement also creates an implicated momentum within the organisation, as management needs the result (Eden and Huxham, 1996; Coughlan and Coghlan, 2002; Reason, 1999; Westbrook, 1995).

In Comparison to Traditional Research

Some key differences to traditional research is already presented above. Below, this is synthesised briefly:

- AR takes action, rather than studies action
- AR involves practitioners, rather than viewing them as actors
- AR is cyclical, unlike more linear traditional research
- AR creates output in action *and* research

In addition to these key differences, some additional contrasts are highlighted below:

Intimacy In traditional research, the researcher distances him- or herself from the phenomenon to be observed. Conversely, in AR, the researcher is directly involved in the organisation (Coughlan and Coghlan, 2002).

Specificity Positivist science focuses on creating universal theories, applicable over contexts. AR on the other hand, creates specific *results that are not generalisable over contexts* (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Voss et al., 2002). The research is said to be *Local Theory*, as suggested by Eden and Huxham (1996). This means that data is interpreted, in resemblance to empirical research, but also embedded (Coughlan and Coghlan, 2002).

Insightfullness AR is described by several authors to provide a degree of insight that no other methods could provide (Eden and Huxham, 1996; Westbrook, 1995). This is especially true for “unstructured ’messy’ problems” (Westbrook, 1995, p. 18).

Testability AR cannot be tested with traditional means, directly implicated by its specificity to a context as explained above (Eden and Huxham, 1996).

There are, however, similarities to traditional research, according to the authors’ understanding. Such similarities lie mainly in the need of rigorous theoretical analysis, as empirical research requires theory not only to conduct research, but also to generalise the results from the research (Flynn, 1990; Meredith, 1998; McCutcheon and Meredith, 1993; Voss et al., 2002). As described by Lewin, as cited in Eden and Huxham (1996, p. 79): “there’s nothing so practical as a good theory”. With this in mind, one need not question the credibility of AR: “AR is a form of science which differs from experimental physics but is genuinely scientific” (Coughlan and Coghlan, 2002, p. 238).

In Comparison to Quantitative Modelling

The authors to this study briefly compared traditional quantitative modelling to action research, as correcting lead-times can be seen as a quantitative problem. In fact, within the area of operations research, Bertrand and Fransoo (2002) mention how quantitative modelling initially was targeted on solving practical problems rather than on generating scientific knowledge. However, the same paper mentions that such modelling do not produce knowledge on processes, as it is studying *one specific instance*. Thereby, the authors found it clear that although quantitative modelling is interesting, it is not well suited for the contextual situation at ChemCo. Such a statement seems to hold even more true when Bertrand and Fransoo (2002) further explain how the main problem with quantitative modelling tends to be implementing the solutions correctly.

In Comparison to Case Studies

Flynn (1990) describes how case studies are commonly used to conduct empirical research. Such studies are "an objective, in-depth examination of a contemporary phenomenon where the investigator has little control over events" (McCutcheon and Meredith, 1993, p. 240), elaborated on in great detail by Yin (2014). These studies are "a fairly close relative" (Westbrook, 1995, p. 16) to action research. Although both methods focus on creating validity for practitioners (Eden and Huxham, 1996; Coughlan and Coghlan, 2002; Voss et al., 2002; Westbrook, 1995), the means of doing so are different. In case research, the researchers is optimally objective and external (Yin, 2014; McCutcheon and Meredith, 1993), whereas in AR, the researcher takes action and is directly involved with the organisation. As an implication, the focus on interviews found in case studies (Voss et al., 2002) is also exchanged for certain dialogue, in this study more so due to the choice of the actors view. In addition, case studies, while examining something intimately, do not carry out manipulations or experimental control (Meredith, 1998).

Noteworthy is how certain authors have developed methodology, inter alia *Systematic Combining*, for iteratively working with case research: the theoretical framework, empirical data and case evolves over time (Dubois and Gadde, 2002). From the authors understanding, this moves case research in the direction of action research, although key differences still exist in how involved the researcher is, the tools used as a consequence, as well as in the dimension of timing.

Suitability for the Study

Earlier in this chapter, the actors view was chosen as an approach to research due to its applicability for creating a solution tailored for ChemCo. Key arguments for that choice included the aspect of conducting real time research, the specificity to context, and also the requirement for certain compromising. In addition, the actors view encourages researchers to "construct the future from within, the researcher[s] being part of such research reality" (Gammelgaard, 2004, p. 481), as described previously, where Arbnor and Bjerke (2009) explain how dialogue is a key tool to conduct research. *It seemed that AR reflected well the requirement and needs of the actors view.*

Ultimately, AR incorporated all of the aspects which lead to the choice of the actors view: encompassing the need for action, the timing aspect, and the need to solve a problem with genuine interest for managers. Additionally, the social reality as explained by the actors view required, according to the authors beliefs, a genuine understanding of both the organisation, context and dynamics at ChemCo - which is described by the AR characteristics. Subsequently, the definition as defined by Coughlan and Coghlan

(2002) well applied to the situation. To illustrate this, the authors decided to relate the four points of the definition to the situation at ChemCo:

1. **Research in Action** It was clear that the research needed be conducted in real time, where lead-times could not be updated without practical action.
2. **Participative** To come up with a technique suitable for ChemCo, the organisation would have to be involved.
3. **Concurrent with Action** In addition, the technique would be developed over time, where practical work and evaluation would have to be concurrent with scientific development to find a suitable option.
4. **Sequence of Events and an Approach to Problem Solving** The fourth point well described the cyclical nature of AR; the researchers needed to take part in the process of action, in order to fulfil the two goals of action research: to solve a real problem and to contribute to academia.

The argumentation above also well applies to the three recommendations presented by Coughlan and Coghlan (2002) concerning when to conduct AR: (1) a series of action would be taken to come up with a technique feasible at ChemCo, (2) such actions should improve the production planning, and (3) in order to develop the technique, change and action were required. Indeed, the practical action research example presented, a bank with a recurring operational issue, well reflected the situation at ChemCo as described by the background. To conclude, after thorough theory examination, *AR did reflect not only the view chosen, but provided the needs required to tackle the problem at hand.*

Relation to Theory Extension Previously, the authors argued why theory extension was suitable for this study; action research relates well to that choice. Eden and Huxham (1996) explain how AR is suitable for studying which theories are usable when there is a real need for action, but how *it often uses old theory and builds on it.* Westbrook (1995) agrees, and argues that AR is the most effective methodology for developing techniques, where the proximity to managers is a main driver.

2.2.3 Qualitative Perspective with Combined Methodology

Research can have a qualitative or quantitative approach (Backman, 2002). However, methodologies used to gather data can also be quantitative or qualitative; data itself can moreover be categorised accordingly (Backman, 2002; Nyberg, 2011). Ultimately, the three definitions are illustrated in Table 2.2.1.

	Quantitative	**Qualitative**
Perspective	Assumes an objective reality	Assumes a socioculturally constructed reality
Methodology	Measures phenomena in number in order to enable the use of statistics	Aims at examining and understanding phenomenon
Data	Illustrated by a number (Ex. age)	Illustrated by words (Ex. gender)

Table 2.2.1: Defining quantitative and qualitative research based on Backman (2002) and Nyberg (2011).

With the definitions in mind, the authors felt convinced that the research **perspective** in itself was *qualitative*, much reflected by the chosen research approach, in accordance with qualitative approaches, views the reality as socially constructed.

As for the **methodology**, the chosen design was found to well align with a *qualitative* methodology, illustrated by the desire to explain a context-specific phenomena. However, *certain quantitative tendencies* could easily be identified, as the researchers still had to conduct numerical calculations for lead-times.

Finally, as for **data**, naturally *both types* of data was used. Such a statement can be verified by how lead-times were described by numbers, whereas subjective evaluations of techniques were provided in words.

Meredith (1998) explains how the research methodologies are not mutually exclusive, and how *combining them can prove even better* than any of the original methodologies.

2.2.4 Induction with Deductive Tendencies

Closely related to the discussion of qualitativity versus quantitativity, another discussion about inductivitiy versus deductivitiy can be found. The concepts of induction and deduction are defined below.

Deduction Based on a theory, hypotheses are formed, and then tested based on logic.

Induction Based on separate real life phenomenon, theories or models are developed (Eriksson and Widersheim-Paul, 2001; Dubois and Gadde, 2002).

Olhager (2016a), in his lectures on the thesis process, illustrates the definitions above. A similar illustration is presented below in Figure 2.2.1.

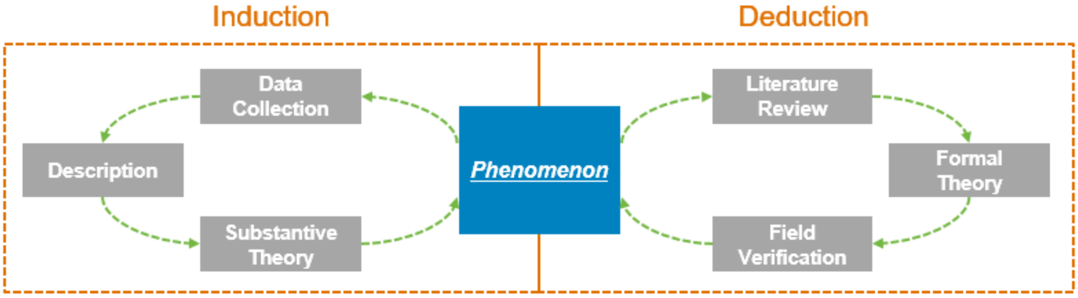


Figure 2.2.1: Induction and deduction as explained by Woofruff (2003) in Olhager (2016a). Illustrated, and thereby modified, by the authors.

More importantly, Olhager (2016a) describes how *inductive research is related to the qualitative approach*, whereby *deductive research is related to the quantitative approach.* In agreement, the authors found that *the inductive approach well suited not only the chosen view, but also the chosen research design.* This as data would be the foundation to answer whether approached would work in ChemCo's situation. Westbrook (1995) further explains that for creativity to lead to theories in AR, an inductive approach should replace the traditional deductive and reductionist approach.

The research included certain tendencies of deduction, where literature and formal theory became a main source for calculating lead-times. Indeed, such approaches were based on a hypothesis of which methods could be suitable. Moreover, certain industry characteristics were required to understand the context, important for the chosen view, which follows the principle of deduction more than induction, although hypotheses were not formally developed.

2.3 Developing a Methodology Framework

> "The most important mission for methodology, then, is to clarify how different methodologies, problem formulations, study plans, methods, techniques and study areas make up the parts of an integrated whole." (Arbnor and Bjerke, 2009, p. 22)

This chapter so far has presented an approach to methodology, and thereafter the choice of a design. To conduct research, these two concepts needs to be integrated to guide the steps and procedures actually carried out. Followingly, this section explains how the authors developed a methodological framework to be used in the study.

2.3.1 General Empirical Framework

Flynn (1990) in the work "Empirical research methods in operations management" presents a general approach to methodology suitable for empirical research in operations management. His linear framework is presented in Figure 2.3.1.

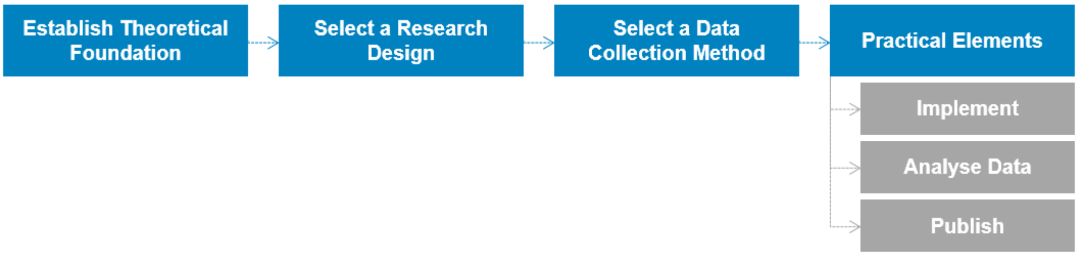


Figure 2.3.1: Four steps for empirical research as suggested by Flynn (1990). Illustrated, and thereby modified, by the authors.

1. **Establishing a Theoretical Foundation** The first step includes getting the necessary theoretical foundation to carry out research. It involves deciding on whether to build or verify theory.
2. **Selecting a Research Design** The second step involves selecting a research design on which to build the next steps.
3. **Selecting a Data Collection Method** Based on the design, data collection methods are to be decided on. These relate to how to get data in practice.
4. **Practical Elements** The final step involves implementing the chosen methodology in practice to actually collect data, where-after it should be analysed. Lastly, the research should be documented and published.

These steps are based on Flynn (1990), with graphical influence from Westbrook (1995). The steps are synthesised and interpreted by the authors. The final step (4) can be seen as one or two seprate ones depending on who presents it, as seen in the two works.

2.3.2 Iterative Steps of Action Research

Action research in practice is described by several different authors as being cyclic, see inter alia Eden and Huxham (1996), Coughlan and Coghlan (2002), and Reason (1999). For understanding, the iterative nature of action research is presented as one example by Reason (1999).

a. Develop Questions In the first step, a common interest is established, where-after questions are developed. Actions to be conducted are agreed upon.

b. Action Agreed actions are put into action in everyday work.

c. Insight As a consequence of action, people involved gain insights: they change their views on the problem at hand, get more understanding, and they come up with ideas for how to move forward.

d. Reflection Lastly, the involved parties gather to evaluate the questions from the first step. Often, the questions are changed, whereupon the cycle starts over with new agreed actions.

The steps are based on how a co-operative research group works as described by Reason (1999), although words chosen to synthesise the information is based on the authors interpretation. A graphic illustration is presented in Figure 2.3.2.

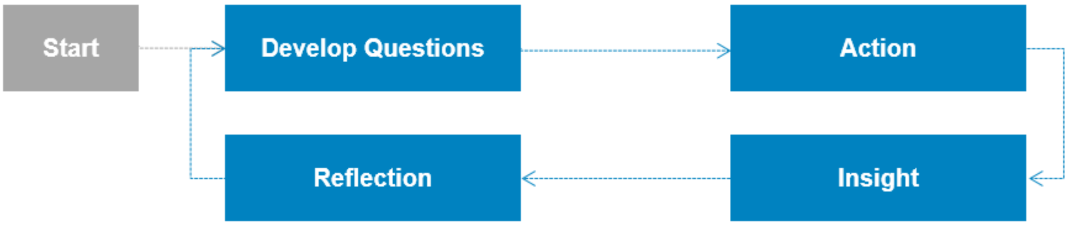


Figure 2.3.2: The iterative steps in co-operative research as suggested by Reason (1999). Illustrated as well as interpreted by the authors.

2.3.3 Action Research Frameworks

When implementing the iterative steps into a methodology framework, new frameworks are developed. Such developments have been made by both Coughlan and Coghlan (2002) and by Westbrook (1995) who each present one framework that can be used to conduct action research. These are presented briefly below.

Framework by Coughlan and Coghlan (2002)

Coughlan and Coghlan (2002) explain the process related to action research in detail, where their model well illustrates the cyclical nature of AR. Their methodology is presented in Figure 2.3.3.

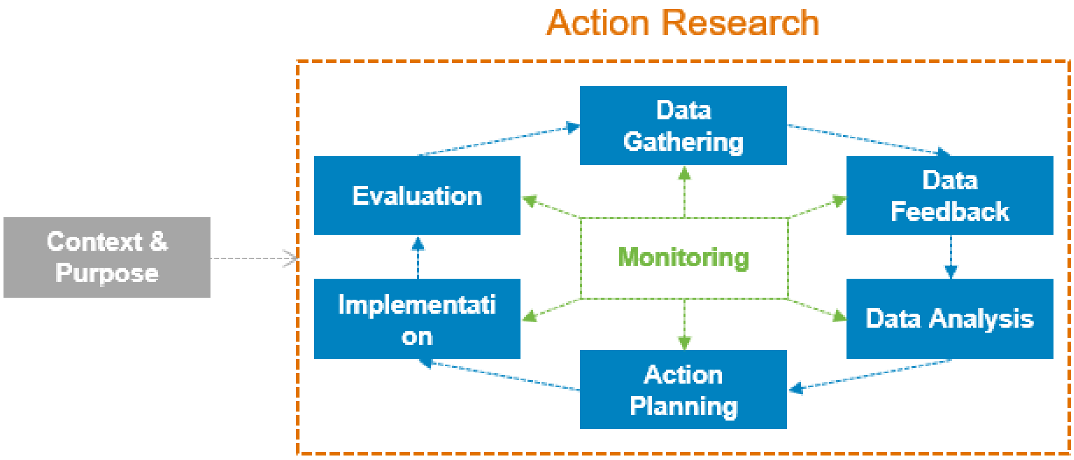


Figure 2.3.3: Action research methodology framework as suggested by Coughlan and Coghlan (2002). Illustrated, and thereby modified, by the authors.

A brief description, based on Coughlan and Coghlan (2002) is presented below.

Context and Purpose Researchers must first understand *what is driving a need for action*: their rationale for their project.

Monitoring An important meta-step is to continuously monitor the iterative process. Often, the steering group and/or managers may not have the available time to engage at detailed level, why this step is of great importance.

Data Gathering Data is gathered dependant on the context as either (1) hard data or (2) soft data. Important to note is that *observations can be formal and informal*, meaning that important data can be gathered over coffee.

Data Feedback Data is fed to the client system for analysis.

Data Analysis The data is analysed collaboratively.

Action Planning A plan for action, including time schedule, is created.

Implementation The organisation implements the action plan.

Evaluation The outcomes of the action are evaluated; both (1) intended and (2) unintended such outcomes may happen.

Framework by Westbrook (1995)

Westbrook (1995) on the other hand follows a general framework, similar to the ones by Flynn (1990). Consequently, according to the authors, it has advantages in how it relates to established frameworks. The framework is illustrated in Figure 2.3.4.

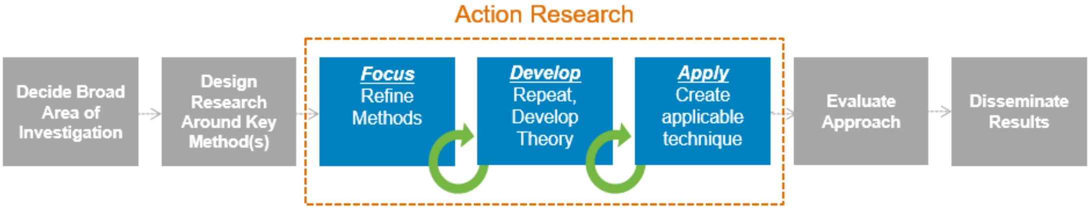


Figure 2.3.4: Action research methodology framework as suggested by Westbrook (1995). Illustrated, and thereby modified, by the authors.

A brief description of the action research elements, based on Westbrook (1995) is presented below:

Focus Once a basic research design is created, a first collaboration takes place: researchers must decide the area of investigation in greater detail, and thereafter refine the research method.

Develop With a refined research method, the method can be repeated, and theory can be developed.

Apply When both of the areas above have iterated, theory must later be expressed as an applicably technique.

2.3.4 Developed Framework for This Research

Given an understanding of general methodology frameworks, what makes action research different, and how adjusted frameworks could look like, the authors decided to develop a methodology framework to guide the research. A short discussion is first presented on the two frameworkes for action research.

In general, the authors appreciated the clear relation to general frameworks and traditional approaches, as can be identified in Westbrook (1995). The extended view, evaluating the entire process, further provides insight regarding the ”the full picture”.

Coughlan and Coghlan (2002) has its advantage in a more detailed description, but also in mentioning the importance of monitoring, which the authors agreed was important. However, for pedagogical reasons, the authors found the cyclical illustration to be mildly confusing, as some readers could interpret the cycles as ”must-dos” in the given order. In contrast, the authors understanding is that steps can lead to each other more dynamically; in example, there are no reason to plan action if the data does not prove to be useful during analysis. The authors believed that Westbrook (1995) better illustrated this nature. The belief was confirmed orally by Dag Näslund, writer of inter alia “Logistics needs qualitative research – especially action research” and “Action research in supply chain management - A framework for relevant and rigorous research”, see Näslund (2002) and Näslund et al. (2010); Näslund is a professor at the department for which the thesis was conducted.

Given inspiration from the frameworks above, and the brief discussion just carried out, a framework was developed. See Figure 2.3.5.

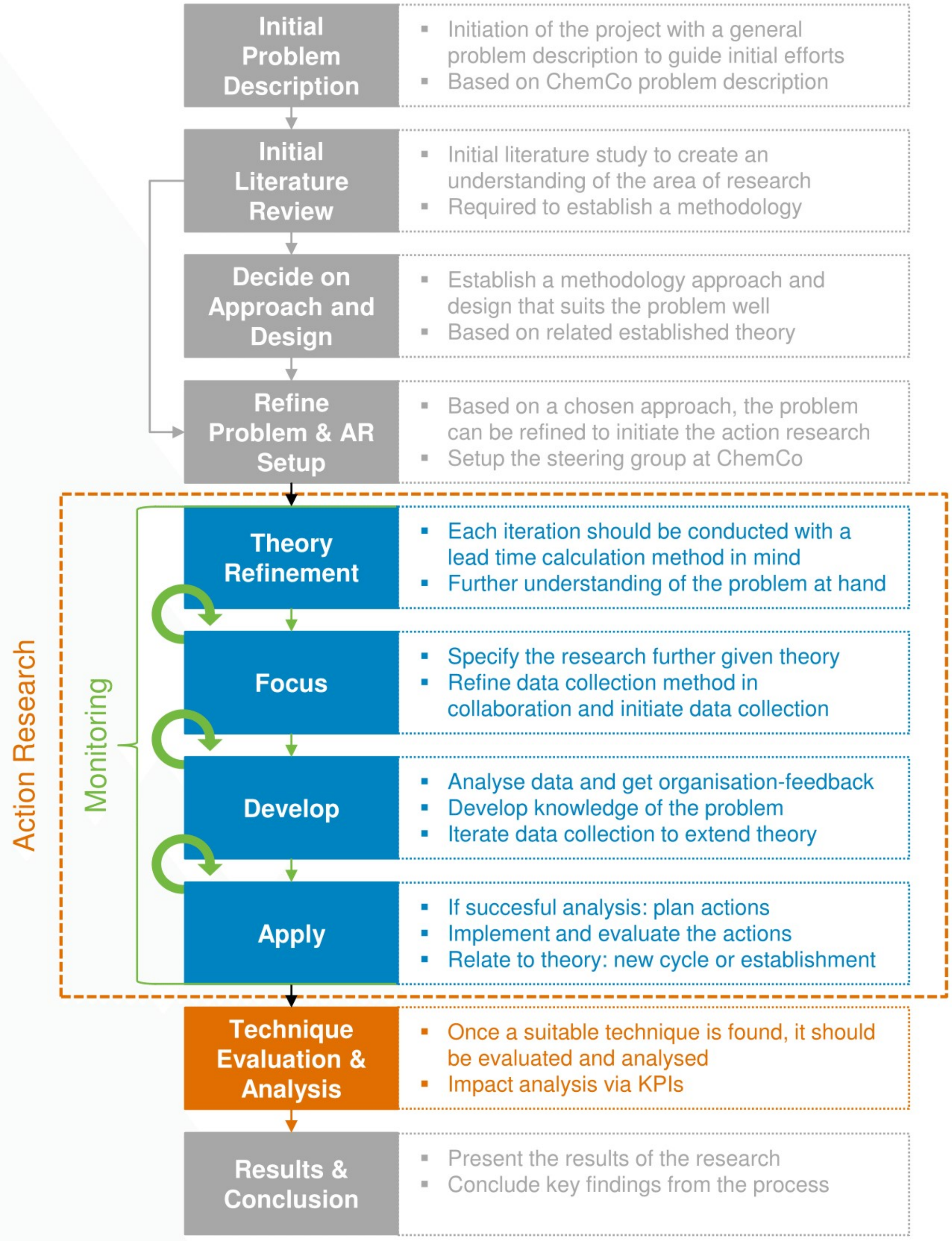


Figure 2.3.5: The methodology framework developed by the authors based on general, as well as action research, frameworks suggested by theory.

Please note how the purposed process combines the two frameworks suggested by Coughlan and Coghlan (2002) and Westbrook (1995), where several of the first-named's detailed steps are included within the more general ones presented. Please also note how a theory refinement step was added to the action research-cycle. This as the authors wished to develop a technique based on a methodology of calculating lead-times.

Based on the importance to relate research to theory, the authors realised that theoretical knowledge on such approaches could guide cycles. Thereby, the focus would be on creating applicability for methods at ChemCo, but also discussing ways to collect data to solve the problem at hand.

Please note that almost all of the initial steps are handled at this stage of the chapter. This follows logically as creating a methodology framework before deciding on an approach and design was not seen feasible.

2.4 Framework in Practice

A framework has now been developed based on theoretical recommendations. However, the framework is not describing all practical details, why this section will focus on key practical steps carried out as part of the research.

2.4.1 Establishing a Steering Group

> *Designed into any action research programme should be a consciousness of the roles to be played by the researcher and the participants* (Eden and Huxham, 1996, p. 81)

Reason (1999) emphasises the need to initiate a project by establishing a group. The step needs to include not only a face-to-face meeting, but furthermore, research methodology must be established. In addition, certain groundrules are needed regarding who should do what. Voss et al. (2002) moreover describe how research should include several persons if no one obvious key informant who can reliable answer all questions is found. The researchers did not find one such person, but instead found that working with the problem at hand required people in several different roles. Thereby, the researchers decided to map stakeholders and employees at ChemCo through dialogue with supply chain managers; as suggested by Coughlan and Coghlan (2002).

Roles Involved

After discussion with the project owner and introductory meetings with key personnel at ChemCo, a steering group was established based on key responsibilities as defined by roles. The roles, excluding the two researchers, are presented in Table 2.4.1.

Key	**Role**	**Description**
PO	Project Owner	Client owner of the project: the SCM Manager
PS	Project Supervisor	A client manager who supervised detailed action
MDO	Master Data Owner	Data owner for data available in the ERP system
PL:P	Planner: Packaging	Planner for packaging material
PL:S	Planner: Salts	Planner for the Salts production category
PEN	Production Engineer	Production Engineer for Salts
ANA1	SCM Analyst 1	Supply Chain Analyst working for the PO
ANA2	SCM Analyst 2	Supply Chain Analyst working for the PO

Table 2.4.1: The roles involved in the steering group for the research.

A short description of the combined group should be presented. The project ultimately has a PO who owns the project: meaning he is ultimately responsible for the problem solution for the organisation. The PO was not involved in detailed actions. Under him, a PS was available, who supervised the project in more detail. The role of the PS was somewhat similar to that of the researchers, but with a focus on the internal organisation, ensuring that adequate resources to solve the problem were invested. The MDO helped concerning technical system questions, as she owned the data in the *Enterprise Resource Planning (ERP)* system. Directly related to the production area, two planners were involved: one planning Salts, and one planning the Packaging used for packaging the materials produced. A production engineer was involved to answer detailed questions, as his responsibility is to fully understand the technical aspects of the production. In addition, two supply chain analysts were involved.

In addition to the main roles presented, a few supporting roles were utilised in a focus group meeting to gain valuable input; roles are presented in Table 2.4.2.

Key	Role	Description
ITE	IT Expert	Responsible for technical aspects of ERP system
DEO1	Demand Owner 1	Responsible for the forecasting done at ChemCo
DEO2	Demand Owner 2	Responsible for the forecasting done at ChemCo

Table 2.4.2: Supporting roles involved at a focus group meeting.

The Researchers' Role

Reason (1999) and Coughlan and Coghlan (2002) both mention the importance for researchers to be contracted as action researchers at the company in order to get access to needed data. This helps greatly with the organisation releasing the value of AR if done correctly. Moreover, it is of particular importance in this type of research, as some people may feel disadvantaged by proposed changed. Ultimately, it is unlikely that all parties will be cooperative (Eden and Huxham, 1996). With this in mind, the researchers early on discussed the potential problem with the PO, who established the role of the researchers within the organisation. To encourage collaboration, the researchers were presented as supply chain analysts and colleagues joining the organisation in order to work with the problem. The researchers found that a major motivator for all involved parties was the importance of finding a solution to the organisation: planners expected it to greatly reduce their workload, while the MDO and PEN explained how their jobs would be made easier as a result.

Voss et al. (2002) mention problems for researchers, where a strong bias can be developed due to the close proximity and consultant-like characteristics of research. Such a bias can influence how observations are viewed. To counteract this, Voss et al. (2002) suggests having more than one person review findings. The researchers tried actively counteracting the problem, by continuously reviewing and going back to literature, as illustrated by the methodology framework. In addition, the researchers independently reviewed sessions and findings, before a collaborative review was conducted. Moreover, the PO and PS were continuously involved in reviewing data. Once again, it should be noted that the PO has a PhD, why he is used to academic research - although naturally, his bias was expected to be more vast than that of the researchers. Moreover, due to the study being conducted as a thesis, actions and research was continuously reviewed and supervised by the thesis supervisor at Lund University.

Finally, Coughlan and Coghlan (2002) present three major guidelines for researchers in AR, briefly presented below.

Apprenticeship Due to hardships in changing the methods used, Coughlan and Coghlan (2002) recommend that researchers take apprenticeship within the organisation. The researchers in this study did so by working close with the PO, who due to his nature as a supervisor of the thesis well fitted such a role.

Journal Keeping AR requires certain degree of orderliness, as briefly presented previously in this chapter. To do so, several authors suggest journal keeping (Coughlan and Coghlan, 2002; Westbrook, 1995). The researchers did not actively have to think about this, as they both prefer continuously documenting progress and reflections while working. Such documentation was reviewed daily before the working day started.

Continuous Learning Finally, Coughlan and Coghlan (2002) emphasise the importance to learn continuously. The researchers did not only agree with this, but tried to actively do so by involving themselves with a vast array of roles at the company, and talking to them about the genuine problems they face. In addition, the researchers continuously reviewed solutions, as well as consulting recommendations, previously provided, or used by, ChemCo.

2.4.2 Reflecting on the Frequency of Site Visits

Westbrook (1995) describes how, in AR, the researchers must reflect and decide on the frequency of site visits. Although it is important to be in close proximity to the problem at hand, the organisation also has to carry out action in order to learn. This was somewhat complicated for the researchers in this study, as research was conducted in another country. Ultimately, this meant that their office space was in the offices of ChemCo. However, the researchers actively spent much time at the headquarters, rather than in Plant A, where the Salts production took place. Ultimately, the researchers ended up spending around one day per week in Plant A, which well reflects an example frequency presented by Westbrook (1995). Thereby, the risks with spending to much time, or too little time, working directly with the problem was believed to be handled in a feasible way given the restrictions at hand.

2.4.3 Deciding on Data Collection Methods

Previously in this chapter, contentions by Eden and Huxham (1996) are presented; among these, one can be found stating that triangulation should be used for AR in order to develop theory. Voss et al. (2002) further agree, stating that reliability of data increases if several sources are used. Yin (2014) agrees and explains how triangulation can be used in order to converge different lines of inquiry. The authors tried actively taking this into consideration when deciding on data collections methods.

In action research, as well as in the developed methodology framework, it is explained that research should emerge. In detail, the focus step should refine the data collection method. Ultimately, this means that data collection methods were not set up in prospect, but rather based on the cycles.

Below, the data collections methods used in the research are presented, with a brief discussion on their applicability.

Intervention

Given the view, design, and framework, intervention followed logically: the researchers involved themselves with the organisation, and carried out experiments with the organisation - meaning that employees of the organisation conducted change experiments in their own setting. During this, the researchers observed the situation, which Flynn (1990) denotes *Participant Observation*: researchers, often known to the organisation, collect and analyse data regarding ongoing change.

Dialogue

Closely related to the actors view and chosen research design, dialogue was used as a key component to gather data. As suggested by Arbnor and Bjerke (2009) and Voss et al. (2002), dialogue became a key information source on a daily basis, as problems were discussed not only on formal occasions, but often throughout the day - sometimes over coffee or lunch. As categoried by Backman (2002), the authors found themselves communicating both in script and speech: face-to-face, over phone, over e-mail or even over chat, where all but e-mails should be regarded as dialogue-like forms of communication. The researchers tried taking notes when possible, and otherwise, synthesising dialogue in retrospect to document views and happenings.

In relation to Interviews Interviews are commonly used in empirical research (McCutcheon and Meredith, 1993; Voss et al., 2002). In case studies, interviews are often backed up by unstructured more informal interviews (Voss et al., 2002). Thereby, interviews can move towards dialogue, according to the authors' understanding. The authors tried carrying out initial interviews, but noted that the formality sometimes created obstacles due to distancing the researchers from the employees. Instead, the authors wanted to work with the employees, as suggested by AR theory, why interviews instead became collaborative problem solving sessions. Such sessions were often prepared by sending out a series of questions in e-mail, as is suggested by interview-recommendations from theory (Flynn, 1990).

Historical Archives

Archival data has an advantage in being unbiased, as providers do not know that they are observed. (Flynn, 1990). This should hold yet more true when data is provided by systems, without any intermediates. Such information was gathered not only from the ERP system, but also from offline file archives which existed at ChemCo. In detail, all information regarding materials, their characteristics, used lead-times etcetera was downloaded by the authors directly, aiming at keeping objectivity high.

In addition to gathering data from internal file systems, the authors spent time looking through historical consulting recommendations at ChemCo.

Field Notes

Voss et al. (2002) describe the importance of taking field notes when working with organisations. Such notes can be taken when happenings occur, and thereby provide a running commentary about the study. The authors found this not only to be helpful, but also natural, as both authors prefer taking field notes when working both in academia and in business, to organise their work and to plan their time.

Both researchers preferred reviewing key field notes daily during early mornings in order to plan their time, and furthermore did so weekly to set up holistic weekly targets.

Workshop

Flynn (1990) describes how *Focus Groups* can be used to collect data: a group of people meet physically, and give their opinions orally to a set of questions sent out before the meeting. A facilitator then asks questions, where discussion is allowed in order to reach consensus. An almost identical methodology to this according to the authors' understanding, is the *Workshop*, which is a term preferred, and a concept common, to employees at ChemCo. Such a methodology was used several times when meeting with the steering group or parts of it, also explained under the interview-paragraph, but also for one larger problem-solving session related to the understanding of lead-times.

The mentioned workshop gathered all roles, as explained earlier in the chapter, to discuss the understanding related to lead-times. It had two main goals: (1) establishing a common understanding of lead-times both physically and in the ERP-system, and to (2) establish a process to improve data quality, used across all production categories. In practice, an extensive presentation was created with predefined questions, which were then walked through during the session.

The workshop-slides used are not presented due to confidentiality reasons, as it includes detailed descriptions of ChemCo's systems and business processes.

2.5 Establishing a Theoretical Understanding

A framework has been established, and the application of it has been described further with a focus on data collection methodologies. However, as mentioned several times, theory foundation is key. This section discusses how such a foundation was acquired.

Backman (2002) mentions three main reasons to conduct an initial study: (1) to get an understanding of the subject, (2) to see what has been done previously within the subject, and (3) to acquire advice on methodology and data collection. Rowley and Slack (2004) add a fourth one, by mentioning (4) how it helps interpret and analyse results. In addition, AR should rely on strong theory to counteract several negative aspects with empirical research (Eden and Huxham, 1996; Dubois and Gadde, 2002). The third (3) of these step has clearly been illustrated throughout this chapter. However, the process to gain knowledge has not been presented.

2.5.1 The General Process

Rowley and Slack (2004) identify key themes in creating a literature review:

1. Scanning documents to gain familiarity and to group themes
2. Identifying key themes and messages through making notes and distilling
3. Commencing a broader structure and working with the understanding of key concepts
4. Distilling the concepts and findings in the authors words
5. Continously building the bibliography

Backman (2002), Eriksson and Widersheim-Paul (2001), Höst et al. (2006), and Nyberg (2011) explain how, early on, the author must identify key words, and combining these in different literature search. Through an initial search based on these and a first filtering of results, such key words are identified and developed. Backman (2002) further mentions how an initial understanding of the subject area can be achieved through consultation of experts, colleagues or institutions, which then provides guidance for the continued literature study. This is related to the first step, whereas other steps explained by Nyberg (2011) are well described by Rowley and Slack (2004). In addition, Backman (2002) provides a close to identical process.

Eriksson and Widersheim-Paul (2001), Nyberg (2011), and Höst et al. (2006) all describe how literature should not only be read and analysed upon the initiation of a project, but rather throughout the project.

Methodology for Reviewing Literature

Nyberg (2011) describes three approaches to gathering information, presented below.

Unsystematic Sometimes, researchers approach methodology unsystematically, by ”walking around” to find information.

Systematic The systematic approach focuses on key words, and the combination of several words.

Chain-linked When relevant literature has been found, chain-like review can be conducted by further examining used references of important literature.

As for concrete advice, Rowley and Slack (2004) present four key methods for reviewing literature, presented below.

Citation Pearl Growing (CPG) Starts from a few documents, where key terms are used to continue the review.

Building Blocks Key concepts are extended through synonyms and related terms.

Briefsearch A few documents are retrieved fast and easy.

Successive Fractions A search withing already retrieved documents.

2.5.2 The Applied Process

The researchers in the study used three key databases to retrieve information: (1) Web of Science by Thomson Reuters, (2) Emerald Insight, and the library (3) LUBsearch, which is Lund University's library, one of the largest ones in Sweden with over 185 databases and 11.500 journals.

Throughout the research, the authors studied literature based on action research cycles, meaning all theory was not reviewed before action.

Process Explanation

Ultimately, the process carried out can be explained in cycles, incorporating the general process and several methodology recommendations from theory. The approach is synthesised in Figure 2.5.1.

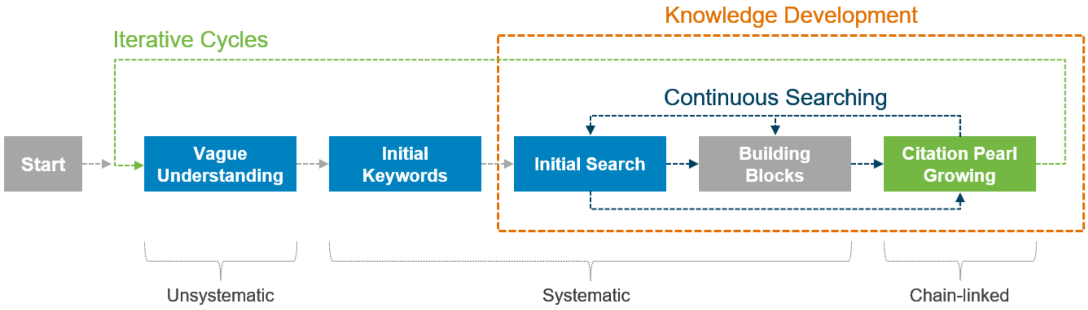


Figure 2.5.1: The cyclic nature of the literature review, as explained by theoretical concepts.

In the beginning of each cycle, the authors had some vague understanding of a concept, a keyword, or a category of literature. Initial unsystematic search, sometimes combined with consultation, lead to the development of keywords which could be used for further searching. These keywords were used in a systematic way in an initial search. Through a first filtering and reading of material gathered, building blocks and CPG lead to further literature searching. During this continuous searching, or sub-iterations, the authors spent time organisaing data and developing knowledge. Sooner or later, through the *CPG*, the authors came in contact with new relevant concepts or keywords, whereupon an entirely new cycle of research began.

The full process was carried out continuously throughout the research, as explained by the methodology framework presented previously in this chapter.

Process-Steps Carried Out

The authors started their process by carrying out an unsystematic approach after consulting with their tutors. This first approach aimed at providing an introductory understand for the entire thesis project. Initially, searchers were made based on keywords related to characteristics of the industry. In practice, keywords such as ”Speciality Chemicals”, ”High Quality Chemicals” and ”Pharmaceuticals Operations” were used. The authors tried using building blocks to identify key characteristics. Additional searches were conducted in material from major strategic consulting firms to build a general understanding needed to set up the AR.

To gain an understanding of how different resources could impact the company, a second iteration included a more systematic approach searching for the theme analytics. ”Supply Chain Resources”, ”Analytics Resources” and ”Resource Interface” were used independently as well as combined with ”Operations Management” and ”Operations”. Through CPG, additional resources were found.

In parallel, methodology literature was studied through initially a building blocks technique focusing on key themes such as ”Research Methodology” and ”Operations Management Methodology”. Through CPG, further literature was reviewed related to inter alia ”Qualitative Research”, ”Empirical Research”, and later also ”Action Research”. In fact, the authors was introduced to AR after realising that case studies were not optimal for the problem at hand.

The third iteration focused on lead-times, where the actual research focus had been established. Initial searches involved the keywords ”Lead Times”, ”Lead-Times”, ”MRP” and ”Production Planning”. The authors used synonyms and related terminology, such as ”Manufacturing Planning and Control”, through a building blocks approach. Through CPG, the authors got introduced to ”Safey Lead-Times”, but also methodology for setting lead-times. This part included several sub-iterations in parallel with the action research to build knowledge needed to develop a feasible technique.

A fourth iteration focused on ”Strategic Segmenting”, to gain knowledge on segmentation. Through, once again, CPG, a sub-iteration focused further on ABC-analysis.

In the fifth cycle, the authors got familiar with ”Campaigning” through the concept of ”Long Lead-Times” and the problematisation of it. Consultation in Lund and CPG finally introduced ”Cyclic Production”.

Journals Referenced

For the report, the authors came in contact with 26 journals in total. A summary of used journals for theory in this study is illustrated in Table 2.5.1 below.

Journal	**Articles (#)**
Intl. Journal of Operations & Production Management	6
Intl. Journal of Production Research	6
Interfaces	4
Intl. Journal of Production Economics	4
Journal of Operations Management	4
Intl. Journal of Logistics Management	2
Intl. Journal of Physical Distribution & Logistics Management	2
Journal of Business Logistics	2
Management Science	2
British Journal of Management	1
Computers & Chemical Engineering	1
Computers and Operations Research	1
Engineering Costs & Production Economics	1
Expert Systems with Applications	1
Intl. Journal of Business Performance Management	1
Intl. Journal of Operations and Production Management	1
Journal of Business Research	1
Journal of Information Technology Case and Application Research	1
Management Learning	1
Management Research News	1
Mathematical and Computer Modelling	1
Omega	1
OR Spektrum	1
Procedia CIRP	1
Sloan Management Review	1
Supervision	1

Table 2.5.1: Journals used to create the theoretical framework used in this study, sorted firstly after frequency used, and secondly in alphabetical order. ”Intl.” denotes International.

In addition, several independent or miscellaneous sources, and 17 books, were used.

2.6 Ensuring Utility

Throughout this chapter, research methodology has been presented in great detail. A framework has been presented and applied, and theory has been explained further. This section focus on making sense and evaluating the research.

2.6.1 Data Validity and Reliability

Arbnor and Bjerke (2009) explain that every scientist faces the challenge of convincing colleagues that results and understanding are supported by the empirical reality from which they are derived. The concepts are presented below.

Validity In research, theoretical understanding needs to be transferred to the reality, which is difficult for all research; validity describes how well a measurement measures what it should, and nothing else.

Reliability Measurements need not only illustrate the right thing, but should do so consistently and reliably: results should be replicable, regardless of researchers conducting it, when following identical methodology (Eriksson and Widersheim-Paul, 2001; Flynn, 1990).

Moreover, validity is often split further into sub-definitions. Such presentations are done inter alia by Yin (2014), who creates such a split for case studies. However, the authors chose to analyse a more generic split, as there are clear differences between case studies and AR, as discussed previously. Such a general split is used by several researchers, where Eriksson and Widersheim-Paul (2001) explain them further:

a. Internal Validity Describes how well notions are in agreement with their operational definitions.

b. External Validity Describes how well operational definitions can be applied in reality (Eriksson and Widersheim-Paul, 2001).

Problematic to Apply Traditional Criteria to AR

Coughlan and Coghlan (2002) does not believe that traditional quality criteria can be fully applied to AR. Eden and Huxham (1996) agrees that AR is not testable in the same ways as traditional research, due to it being context-specific. Coughlan and Coghlan (2002) recommend non-positivist criteria as presented by Reason (1999), presented below as interpreted by the authors:

- Does the AR reflect the collaboration between the researchers and organisation?
- Is the project constantly and iteratively reflected upon?
- Does the research include the necessary knowing to use theory correctly, extend our knowing, and carry out research according to appropriate methodology?

- Is the AR part of significant work within the organisation?
- Does the AR produce results that are new and enduring?

These questions were used proactively in the research to counter validity-related problems. In practice, the authors further realised and emphasised the importance of monitoring the AR, but also to base their research on appropriate methodology after first having acquired a rigid understanding of methodology recommendations. Ultimately, the methodology framework became a key tool to ensure integrity of the study. In addition, the importance of feasibility for the final recommendations was further emphasised, not only for the organisation, but also for it to contribute to academia.

Certain Applicability Exists

Even though positivistic critera might not work, certain applicability can be found. Coughlan and Coghlan (2002) mention that AR does not have more threats to validity than traditional research, but need still recognise and confront risks. Certain impacting themes for validity are discussed below.

Bias One main risk, as explained by Flynn (1990), is ensuring that theories are understandable to others. Meredith (1998) explains how this is problematic, as understanding is not without bias or cultural taint. Thereby, a bias may exist for researchers, as they are tightly linked to the context in which they operate. Coughlan and Coghlan (2002) mention the impartiality of researchers as the main problem to validity. From the authors' understanding, this would become mainly a problem for (a) internal validity, why the language used, and explanations for concepts, must be clearly presented in the study.

Cyclic Research Eden and Huxham (1996) and Westbrook (1995) agree that validity for research is naturally increased when conducted in cycles; ultimately, misunderstandings and wrong assumptions, which the authors believed applies to both (a) and (b), can get exposed and corrected several times, rather than just initially.

Proximity Eden and Huxham (1996), Flynn (1990), and Voss et al. (2002) mention significant advantage for qualitative research in how (2) external validity naturally becomes high, as it takes place in a natural setting. As Eden and Huxham (1996) explain, the research is grounded in actual action. Thereby, subjects have to commit, why they present thoughts which really matters, and not hypothetical ones. In other cases, post-rationalisation can be a significant problem (Voss et al., 2002).

Triangulation Voss et al. (2002) and Yin (2014) explain that triangulation can help increase validity, as several methods are used to study the same phenomenon. Ultimately, reliability of data gathered increases if multiple methods are used to gather it. This is further supported by the contentions presented by Eden and Huxham (1996).

Theory Foundation Another contention as presented by Eden and Huxham (1996) mention the importance of establishing the research in theory. Dubois and Gadde (2002) explain that relying strongly on theory will indeed boost validity.

Ultimately, the researchers needed take into consideration their bias when conducting the study and actively confront it by working with clear concepts and explanations. Moreover, they could do so cyclically, in order to sort out any misunderstandings or wrongdoings. The researchers further based research on a rigid theory foundation, and used several types of methodologies to gather data. By doing so, advantages from proximity could fully be utilised, while disadvantages were countered.

2.6.2 Contributing to Science

As mentioned throughout the methodology, AR is context-specific. Thereby, certain problems exist in generalising results (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Voss et al., 2002). To counter it, building on theory can greatly help, as empirical results can be generalised based on established theory (Flynn, 1990; Meredith, 1998; McCutcheon and Meredith, 1993; Voss et al., 2002).

Bertrand and Fransoo (2002) explain that contribution to science through empirical research can happen both by (1) using well-known solutions to a new process or problem, and by (2) providing new insights regarding a problem that has been studied. Coughlan and Coghlan (2002) explain how such a contribution can emerge over time in AR: contribution to knowledge is incremental. The authors believed that certain generalisability could be granted through how techniques for calculating lead-times were based on theory. Meanwhile, they aimed at providing new insights by developing a technique which worked at ChemCo.

Ultimately, as mentioned by Meredith (1998), generalisation requires an inductive process, why there is no reason that quantitative results should be more generalisable than qualitative ones. Therefore, the authors aimed at truly using the in-depth character of the study to provide and extend knowledge.

Finally, the authors needed to keep in mind to explicitly formulate what readers should take from the study (Eden and Huxham, 1996), as understanding is not without bias or cultural taint. Indeed, the authors needed to work actively towards building both validity and reliability, as it would not only work towards a more trustworthy study, but also help for generalisation.

Chapter 3

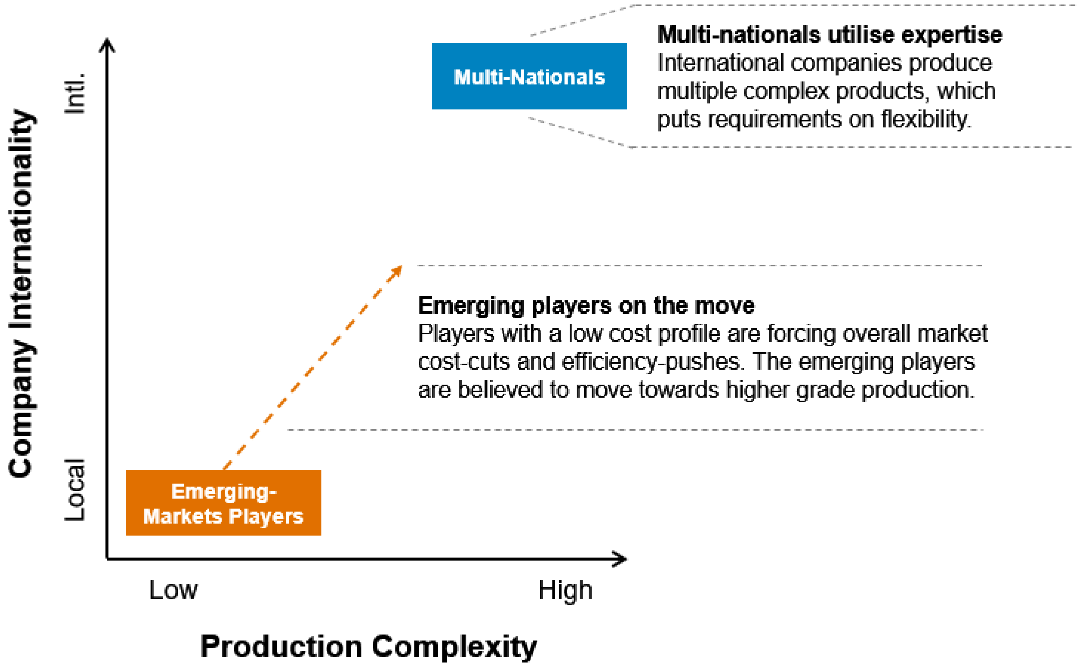
Theory

3.1 Characteristics of the Speciality Chemical Market

This section will briefly introduce the speciality chemical market, characterised by multiple products, multi-stage operations, variability in demand and limited resources. Demand on flexibility, with companies producing a wide variety of products, forces the industry to work mostly with batch production and pressures companies to cut costs. Companies need to increase supply chain efficiency by implementing lean ideas and operations improvements (Grunow et al., 2002; Susarla and Karimi, 2011).

According to Gocke and Lang (2015), the market for speciality chemicals is dominated by multi-national corporations, with the base chemical and plastics market being dominated by emerging-market players. Multi-national corporations have evolved to create more complex and higher grade products, as they find it hard to compete with the low cost profile of emerging-market players; on the high grade, speciality chemical market, multi-national corporations can compete with expertise. Gocke and Lang (2015) believe that emerging-market players will move into the high grade, speciality market as these materials generally are more profitable. In addition, local emerging markets showcase an increasing demand for such products. Consequently, the main challenge for multi-national corporations is to become more cost efficient, should they wish to keep their competitive advantage (Gocke and Lang, 2015; Budde, 2011).

The market, based on company characteristics, is described in Figure 3.1.1.



Multi-nationals utilise expertise
International companies produce multiple complex products, which puts requirements on flexibility.

Emerging players on the move
Players with a low cost profile are forcing overall market cost-cuts and efficiency-pushes. The emerging players are believed to move towards higher grade production.

Figure 3.1.1: The Speciality Chemical Market illustrated based on company characteristics.

3.2 Business Process Theory

This section aims to introduce a theoretical view of business processes, and how new processes ought to be developed. This is of high importance not only to understand the production processes at ChemCo, but also because it allows for certain understanding concerning what is required for a new technique to be successful.

First, business processes need be defined:

> “A collection of activities that takes one or more kinds of input and creates an output that is of value to the customer.” Hammer and Champy (2002, p. 35)

In addition, there can be indirect and supporting processes, helping create value to the customer (Hammer and Champy, 2002).

3.2.1 The Need for a Business Process Perspective

Rummler and Brache (1991) claim that business processes are central in a firms work to improve its offer and its internal functions. They further explain that for change in processes to be successful, it is essential that all functions, affected directly or indirectly, to be involved in order to avoid passing blame between functions and implementing change faster and more effectively. N. Damij and T. Damij (2014) state that the complexity of modern firms, with key processes, support processes, and sub-processes make it difficult to analyse activity without a business process perspective. Ljungberg and Larsson (2012) press on the importance of understanding the customer needs in order to develop well-functioning procceses.

3.2.2 Changing a Process

Rummler and Brache (1991) present three steps to successfully identify and substitute an old process with a new process. In the first step, *Key Process Identification*, a process that is in need of improvement is identified. In the second step, *Process Improvement*, the process is analysed by a team, where the quality tends to increase with cross-functional teams. The current process is understood, mapped and changes are suggested. In the third and final step, *Ongoing Process Improvements and Management*, the performance is monitored and evaluated. New opportunity for change is identified and acted upon. A process owner is chosen to make sure the process continues to improve and that the change last. The process is visualised in Figure 3.2.1.

Figure 3.2.1: A three step model on how to effectively and efficiently implement changes in an organisation, presented by Rummler and Brache (1991).

In contrast to the gradual improvement suggested by Rummler and Brache, Hammer (1990) and T. Davenport and Short (1990) discuss the power of reenginering a process rather than adjusting and improving an old process. Rejecting old assumptions and processes have shown to improve performance significantly. A key principle for successful innovative process work is to *organise around outcomes, not tasks* (Hammer, 1990). By focusing on the task to be performed, process innovation can discard old processes, assumptions, and ways of thinking. Doing so, it is possible to discover new ways to solve the same problem, hopefully improving efficiency and/or effectiveness (Hammer, 1990; T. Davenport and Short, 1990).

N. Damij and T. Damij (2014) argue that the incremental approach to improving processes is a good choice when a process is working and is in need of higher efficiency or ways to increase performance. T. H. Davenport (1993) argues that the incremental approach does not require as much effort as the innovative reenginering approach. It is also associated with a significantly lower risk and projects usually become shorter.

3.2.3 Maintaining Improvements

One of the major risks involved in developing new processes is the risk of the new or improved process not being recognised by the organisation, and the organisation thereby returning to the replaced process (Laguna and Marklund, 2013; Ljungberg and Larsson, 2012). According to Laguna and Marklund (2013), a key success factor for getting good results and maintaining improvements, is to define clear responsibilities for changes. In a cross-functional team, the responsibilities should ideally be distributed over several, or all, departments. A process owner should be chosen, helping with cooperation between functions, as well as monitoring the progress of the project; this person does not necessarily have to be chosen beforehand. Ljungberg and Larsson (2012) press that the owner should not only monitor the performance of each sub-task and facilitates information flow, but also focus on the end result.

Bourne et al. (2003) discuss the difficulty in finding suitable measurements that measure activities optimally. They argue that it is easier to find suitable measurements when having a clear goal with the process improvements. They also state that it is essential for the measurements to be aligned with company goals.

3.3 Analytics' Impact on Supply Chain Performance

Analytics are becoming increasingly important as a basis for decision making in firms (Liberatore and Luo, 2010). Data quality is key in order to efficiently and effectively use analytics (Dionne and Kempf, 2011). This section aims at introducing the concept of analytical resources, their interfaces, and how they relate to supply chain.

3.3.1 The Resources of Supply Chain Analytics

Chae et al. (2014) investigate the growing importance of *Supply Chain Analytics* for operational performance. It is defined as *the integration of three sets of resources: Data Management Resources*, *IT-based Planning Resources* and *Performance Management Resources* all provide significant contribution to operational performance.

Data management resources are resources which aim to maintain or improve the quality of supply chain data in the system, including cleaning of data, acquisition of new data, storing, retrieval and systematic maintenance. This is IT-supported and should be considered the backbone on which supply chain analytics rest. IT-based planning resources are resources which use the data available to perform analysis or assist in analysis of the data, such as mathematics, simulation and machine learning. Performance management resources are process and performance improvement methodology and technology, focusing on closing the gap between planning and execution.

The three components are illustrated in Figure 3.3.1.

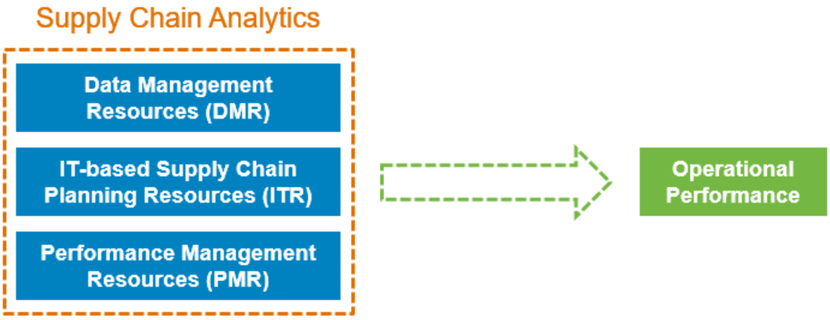


Figure 3.3.1: A schematic by Chae et al. (2014) showing how Supply Chain Analytics, id est data management resources, IT-based planning resources and performance management resources, leads to operational performance. Illustrated, and thereby modified, by the authors.

Top performing firms are better than peers at utilising the resources effectively (Chae et al., 2014; T. Davenport and Harris, 2013); Liberatore and Luo (2010) found that top-performing firms are 50 percent more likely to use analytics in decision making.

Data management resources enables the integration of IT-based planning resources; data management therefore is essential to harness the full capacity of IT-based planning resources, such as an ERP-system. Should the data quality be poor, the analysis will be skewed and the results may not lead to right conclusions. Therefore, data management is critical for IT-based planning performance (Chae et al., 2014). This position was verified by the source, showing that data management correlated positively with IT-based planning. Ultimately, *supply chain analytics as a whole is shown to correlate positively with supply chain operational performance* (Chae et al., 2014).

3.3.2 Interfaces Between Resources

According to Samaranayake (2013), inefficiencies and ineffectiveness occur in the interfaces between resources. Inefficiencies are generally time and processing power spent bridging two systems, and are moreover generally due to data not being treated equally throughout systems. Significant effort needs to be spent maintaining, servicing and improving data in order to get good results. Should input data quality be poor, output quality will suffer (Dionne and Kempf, 2011).

Recently, many SMEs have opted for integrated *Manufacturing Planning and Control (MPC)* systems as part of their ERP-system. This has shown to have advantages in integrated data, eliminating inefficiencies in interfaces between systems. Academia has, since long, recognised the importance to improve MPC systems in order to improve the competitiveness of firms (Samaranayake, 2013).

3.3.3 Forecasting

According to T. Davenport and Harris (2013), high performing firms are internally using forecasting analytics effectively to create competitive advantages. Forecasting analytics are cutting costs while making the supply chain more responsive and agile. This section aims at further describing the concept.

The quality of forecasts can significantly affect analytics requiring the forecast as input. Bullwhip effects and net stock amplification are common results. Poor demand forecasts lead to overall increased supply chain costs. This is due to the addition of an extra uncertainty, the forecast uncertainty (Jaipuria and Mahapatra, 2014). In order to minimise bullwhip effects, it is of importance that all instances of a supply chain have the same data. Usually, supply chains are too complex and the parts of the supply chain are secretive and reluctant to share information, both internally and externally. For this reason, companies utilise forecasting to get an estimate of future demand.

3.4 Lead-Times

This section aims at introducing the theoretical concept of lead-times. Lead-times are of high importance for the thesis, as a thorough understanding is required in order to allow for modification or recommendations concerning how they should be calculated.

Lead-times describes *the budgeted time it takes to produce a material*, including procurement of raw materials, but also quality control (Samaranayake, 2013). Often, *Material Resource Planning (MRP)* systems assume such times to be constant, relying on inter alia infinite capacity in production. In reality, lead-times are often highly dynamic and depend on complex operational parameters (Milne et al., 2015). Many MRP or MRPC systems, SAP included (SAP AG, 2001), can recalculate lead-times based on volumes, but are constant in regards to other components (Samaranayake, 2013). Customer lead-times are by Kenyon et al. (2016) defined as the elapsed time between when a customer places an order to the time that the requested product or service is delivered, which should be separated from ”lead-times” or ”internal lead-times”.

Academia has recognised the importance to update lead-times in order to achieve various performance measures, including, but not limited to, on-time delivery, but also productivity and quality (Samaranayake, 2013). Lead-times and lead-time performance is a key factor for getting future orders, according to Kenyon et al. (2016).

3.4.1 How Lead-Times are Used

The MPC system works to provide effective planning *and* execution of the planning (Samaranayake, 2013). Lead-times are often used in one part of the MPC to offset *Net Requirements*. Such offsetting creates both manufacturing releases and planned purchase orders prior to the required delivery date. This method, the MRP method of planning, is often used, with 75 percent of manufacturing companies using it as their method of materials planning (Milne et al., 2015). One reason behind its high usage is the comparative advantage in simplicity compared to more mathematical approaches. Moreover, MRP shows a clear input-output relational methodology, something many users prefer and have an easier time grasping than ”black box”-like mathematical models (Milne et al., 2015). Furthermore, many ERP systems, SAP being one example (SAP AG, 2001), include MRP-functionality (Milne et al., 2015) as part of their production planning support (Samaranayake, 2013).

As part of the MRP, *Master Scheduling* exists as a function with the goal to create the master plan per SKU: how much to produce of a particular material in a given timeslot. In some systems, such scheduling can happen on a very low level, although detailed planning is often carried out by individual operators (SAP AG, 2001; Milne et al., 2015). Master scheduling takes new customer orders into account, calculating net requirements if needed. The net requirements describe required input, excluding what is on hand, to produce an item. In the system, this is often done through exploding the *Bill of Materials (BOM)*. The system plans the highest possible level, and then walks through lower levels in order to plan ingoing materials to each level. Id est, the finished good is planned before its ingoing components, which in turn are planned before its ingoing components or raw materials (Milne et al., 2015). In practice, net requirements are shown as production orders and planned orders (SAP AG, 2001).

Due to the technical procedure of exploding the BOM, lead-times for finished goods are directly dependent on lead-times of ingoing components. However, due to limited computational resources, many ERPs do not provide capability to calculate lead-times through the use of a BOM (Samaranayake, 2013). Often, it is not done at all, or offline outside of live MRP-calculations, which SAP can do with its *Advanced Planner and Optimiser (APO)* (Samaranayake, 2013; SAP AG, 2001).

With the purpose of the MRPC in mind, it can be stated that it is highly related to performance measures. Samaranayake (2013) describes this to hold particularly true for on-time delivery.

3.4.2 Methods of Setting Lead-Times and Their Consequences

This subsection aims at describing methods for setting lead-times, including common pratices, as well as their anticipated consequences as suggested by academia.

Introducing Slack in Lead-times

Lead-times used by companies often includes *"Slack"* in order to assure feasible planning (Milne et al., 2015). By adding slack, or a safety buffer, the company utilise *Safety Lead-times* which increases the chance that delivery times become shorter than promised lead-times. The uncertainty in the delivery accuracy is mainly driven by the accuracy of the forecast, variability in material processing time, and degree of congestion (Milne et al., 2015; T. J. v. Kampen et al., 2010; Buzacott and Shanthikumar, 1994).

Safety lead-times relate closely to *Safety Stock*, and together, they are used to deal with variability in production capacity and demand in capital intense industries; *the goal is to maintain service level when forecasts are inaccurate* (Milne et al., 2015; T. J. v. Kampen et al., 2010; Buzacott and Shanthikumar, 1994). Quantiles can be used for deciding on safety buffers (Buzacott and Shanthikumar, 1994).

Conversely to safety lead-times, decreasing lead-times can create problems in how actual lead-times empirically tend to increase, causing problems in forecast accuracy and inventory inflation. Thereby, “appropriate selection of [lead-times] is important for cost-effective production planning in MRP systems” (Milne et al., 2015, p. 221).

Performance for Safety Measures Hegedus and Hopp (2001) suggest that safety lead-times should be used to deal with uncertainty in timing, while relatedly safety stocks should be used to deal with uncertainty in volume. Angling the problem somewhat differently, Buzacott and Shanthikumar (1994) suggest that safety stock is preferred to safety lead-times when it is possible to do accurate forecasts of future shipments. T. J. v. Kampen et al. (2010) conclude that safety lead-times lead to higher delivery accuracy when operating under uncertain supply, whilst safety stock increases delivery performance the most when demand is uncertain. If both types of demand is uncertain, safety lead-times is the preferred countermeasure.

Uncertainty in demand can be factorised into changes in order size, changes in order type, and changes in order sequence. A typical source of uncertainty in supply could be machine breakdown.

The recommended use of the two methods of buffer is summarised in Table 3.4.1 and key sources of uncertainty in Table 3.4.2

Buffer Type	**Uses**
Safety Lead-times	To buffer for *uncertainty in timing and supply*
Safety Stock	To buffer for *uncertainty in volume*, *uncertainty in demand* and improve performance when having access to accurate forecasts of future shipments

Table 3.4.1: A summary of when safety lead-times and safety stock is the preferred method of buffer according to Buzacott and Shanthikumar (1994), Hegedus and Hopp (2001), and T. J. v. Kampen et al. (2010).

Uncertainty	**Key Drivers of Uncertainty**
Uncertainty in supply	Machine breakdowns, supplier reliability
Uncertainty in demand	Changes in order size, changes in order types, changes in order sequence

Table 3.4.2: A summary of key drivers of uncertainty in supply and demand according to T. J. v. Kampen et al. (2010)

Academia Suggests Three Ways for Setting Lead-times

Academia has explored several methodologies for setting lead-times, which based on Milne et al. (2015) can be categorised in three groups: (1) analytical, (2) simulation based and (3) mathematical. The first, analytical approaches, aim at determining lead-times based on operational variables. Although simple, many contexts are far to complex to be feasibly modelled analytically. An analytical approach would calculate the actual time required before shipping the material and models all parameters relevat tot calculate this time. The second, simulations, treat lead-times as parameters in several types of operating context. Finally, the third, mathematical approaches, seem to be yet more comprehensive in covering a wide array of operating contexts (Milne et al., 2015). Notwithstanding, such mathematical models often adds complexity. As a result, comprehensive assumptions are often needed, yielding models inappropriate for practical use (Milne et al., 2015; Hegedus and Hopp, 2001).

The three approaches are illustrated in Figure 3.4.1

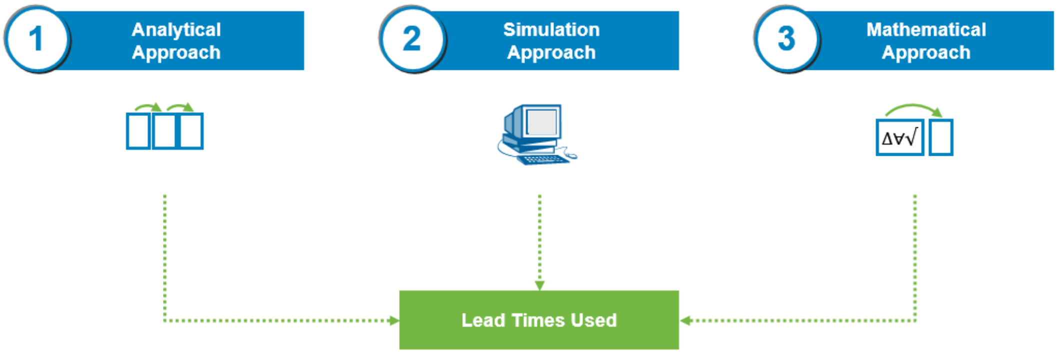


Figure 3.4.1: Illustration of different approaches to determine lead-times, suggested in literature

Stochastic Models Require Simplifying Assumptions

Some authors argue that lead-times should be set with stochastic models, often updated dynamically, sometimes as often as on a per-order-basis. Many such models require simplifying assumptions, such as ignoring backlog, or assuming only certain time-periods. Many of those mentioned models aim at minimising the cost associated with lead-times, including, but not limited to, holding costs, production cost and re-order costs (Milne et al., 2015; Hegedus and Hopp, 2001).

Total Processing Time Often Used as Basis

A common practice in setting lead-times is to do it based on a multiple of total processing time, which can be further complemented by taking costs into consideration. Such approaches can prove helpful, but must be validated over long time-periods, as the impact can be delayed and over long periods of time (Milne et al., 2015).

One should carefully use such an approach, as studies have found that lead-times have a stronger effect on service level than inventory, meaning that shorter times may harm customer service greatly while marginally reduce inventory. As a result, it is important to not use a single measure as a tool for validating lead-times (Milne et al., 2015).

Lead-Time Syndrome Describes Unanticipated Consequences

When updating lead-times, certain carefulness must be exercised, due to the so called *Lead-Time Syndrome* (LTS). The syndrome describes how adjustments in lead-times tend to cause unpredicted increase in process variability, hence reducing service level. Such variability is current short-term. However, companies may carry out consequent adjustments in order to counteract the increased variability, which in turn increases variability even more - a vicious cycle. Ultimately, “it can be summarized that the LTS causes instability, and should therefore be avoided” (Bendul and Knollmann, 2015, p. 81). The cycle is illustrated in Figure 3.4.2.

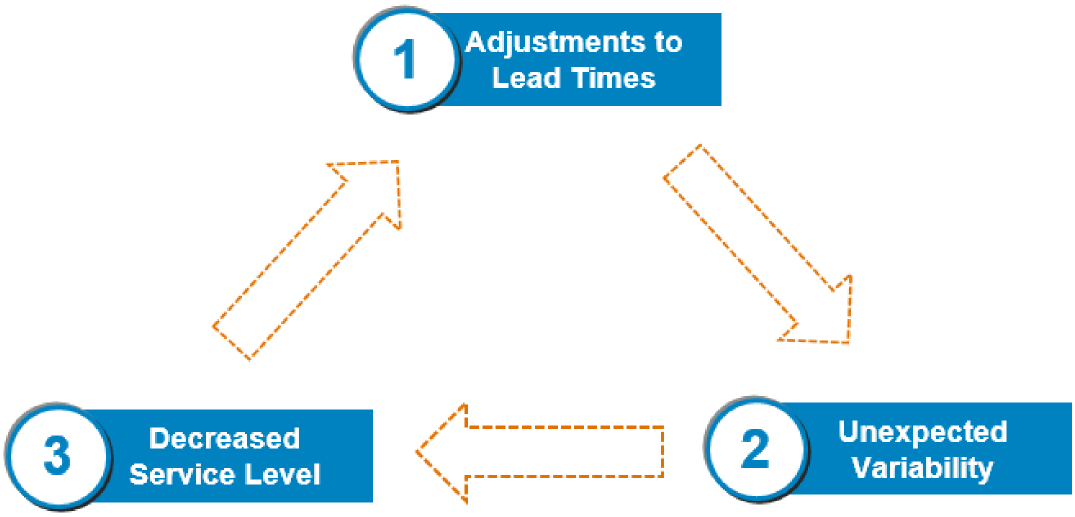


Figure 3.4.2: Illustration of the Lead-Time Syndrome.

In practice, variability often appears as planners adjust lead-times upwards due to low service level, which causes increased workload, which increases work in progress materials, and hence increases lead-time and process variability. This effect in turn causes service level to decrease, which planners again try to adjust by modifying lead-times: reinforcing the problems once again, ultimately causing instability (Bendul and Knollmann, 2015).

To counteract LTS, several authors has shown that “a lower frequency [of updates] would decrease lead-time variability and hence decrease the impact of the LTS”: however, the optimal update frequency is still an open research question, and infrequent updates may cause problems in system disturbances (Bendul and Knollmann, 2015, p. 83).

3.5 Strategic Segmenting of Products

Segmenting the supply chain is an effective way to provide a good service level to the customers while keeping costs and working capital down. This section introduces the concept of strategic segmentation.

The supply chain serves two functions: a (1) *Physical Function* and (2) *Market Mediation Function*. The prior describes the conversion of raw materials into finished goods, including the transportation of all material involved in this process. The latter instead focuses on supplying the market with a variety of products that they wish to buy (Fisher, 1997). When providing a range of products to different markets, the supply chain strategy should be aligned with the characteristics of each product and market in order to satisfy the customer needs (Christopher, Peck, et al., 2006). To meet demands of an agile and volatile market, it is imperative to have a responsive and agile supply chain. This allows for the organisation to handle variability and surprises. If the market is slower and the demand does not vary greatly, a lean approach is usually better, sacrificing some of the agility for cost efficiency (Christopher and Towill, 2002).

Jin and Gilligan (2014) state that segmentation is based on attributes of SKUs, and that the segmentation leads to different inventory and production policies. Segmentation allows for an efficient process where policies can be determined on a segment-level instead of a per SKU-level.

As of today, only little research exists as for how firms should use classification to support production strategies. In fact, most literature focuses on classification from an inventory management perspective - there are only a few papers discussing segmentation from a manufacturing perspective (T. v. Kampen et al., 2012). However, one approach to classification for manufacturing is presented:

> “A particular direction could be to study the inclusion of set-up costs and the related cyclical production plans in process industries as the production interval on a recipe SKU classification level influences the production interval on a SKU level” (T. v. Kampen et al., 2012, p. 19)

T. v. Kampen et al. (2012) define two questions needed to create a classification:

1. How many classes should be used?
2. How are borders between classes determined?

Both of these questions are considered management decisions.

T. v. Kampen et al. (2012) present four main categories of SKU characteristics: *Volume*, *Product*, *Customer* and *Timing*, which can reate borders between classes. There are two main techniques for such segmenting: *Statistical* and *Judgemental*.

Below, some key segmentation methodologies are introduced.

3.5.1 ABC-Analysis

According to Flores and Whybark (1986), *ABC-analysis* is one frequently used tool for segmenting products from an inventory management perspective, using volume as the segmenting characteristic. ABC-analysis is based on the *Pareto Assumption*, stating that 80 percent of revenue is derived from 20 percent of products. With this in mind, the technique segments products into three categories: A, B and C. The products which are contributing the most revenue are classified as A, which then receive more attention. Managerial input is used in the final stage to revise the segmentation.

While traditional ABC-segmentation only considers annual revenue as basis for segmentation, it has also given birth to the augmented and developed *Multiple Criteria ABC-Analysis*. Such a technique, or such approaches, make segmentation more effective for product portfolios that are not homogeneous, or simply very large (Flores and Whybark, 1986; Liu et al., 2016). Ramanathan (2006) presses that one-dimensional ABC-segmentation only works with homogeneous portfolios and for products which only differs in the annual use dollar value.

Flores and Whybark (1986) argue that organisations need to choose criteria based on organisational priorities. Moreover, they present some recommended bases for segmentation that are commonly used. Lead-times and substitutability are commonly used when segmenting purchased products. Criticality, repairability and substitutability are commonly used for maintenance parts. For parts and materials used in production, dollar usage and commonality are suggested. Moreover, they present some commonly used bases for segmentation in ABC-Analysis, presented below:

- Inventory cost
- Part criticality
- Lead-time
- Commonality
- Obsolescence
- Substitutability
- Number of yearly requests
- Scarcity
- Durability
- Substitutability
- Repairability
- Order size
- Requirements
- Stockability
- Demand distribution
- Stock-out penalty cost

Once bases for segmentation have been chosen, several methods are available for weighting the result from dimensions in order to obtain a working segmentation. The methods require qualitatively ranking the importance of the different dimensions in order to finally get a qualitative or quantitative weight for each dimension (Liu et al., 2016).

3.5.2 Innovative and Functional Products

Fisher (1997) discusses the importance of the physical function and the market mediation function of the supply chain for different types of products. *Innovative Products*, products that offer extra value to the customer in order to differentiate itself from the

Functional Products, demands more from the market mediation function. The reason is demand that is usually unstable and hard to predict, but also life cycles that tend to be shorter. Moreover, demand usually shows to be more stable with long life cycles. For functional products, high pressure is put on supply chain efficiency, as competition usually is fierce, why margins are low. The relationship between product types and main focus of strategy is demonstrated in Figure 3.5.1.

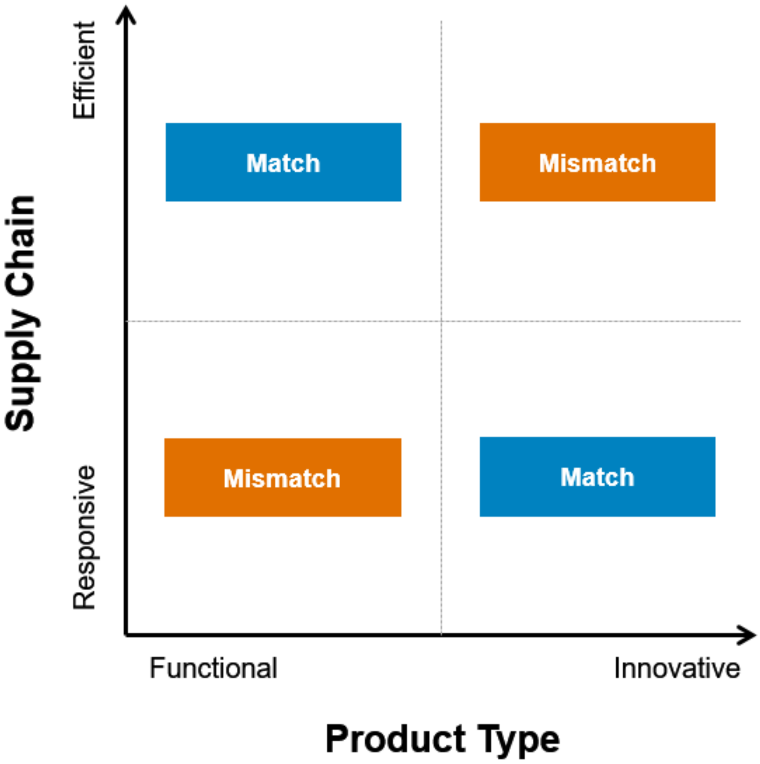


Figure 3.5.1: Figure showing the strategic importance of efficiency and responsiveness for innovative and functional products (Fisher, 1997).

3.5.3 Three Dimensional Model

Christopher and Towill (2002) claim that the *Total Replenishing Lead-Time (TRLT)* is a key driver of any supply chain strategy. They have researched how the product strategy should adapt to the characteristics of the market. Ultimately, they describe three dimensions important when designing a supply chain strategy: (1) *Product Characteristics*, (2) *Demand Characteristics* and (3) *Replenishment Lead-Time.*

Product characteristics are important to consider as the manufacturing process can differ greatly between different products, affecting supply variability and lead-times. Explaining also why replenishment lead-times are important. Also to be expected is differences in profit margin between products, where generally fulfilling orders with higher margins are of higher importance. Demand characteristics are important as they affect the needed supply chain to provide desired service level; unstable demand will increase the need for buffers and tend to increase working capital.

Kenyon et al. (2016) state that delivery performance is of importance in order to increase chances of customers placing more orders.

Closely related to the model by Fisher (1997), Christopher and Towill (2002) suggests that firms operating under uncertain demand has a higher need for an agile supply chain. When demand is stable and products are standardised, it is instead a lean supply chain that is important.

On a final note, one should also consider the three dimensions of the logistics problem: *Replenishment Level*, *Time* and *Distance*, as these dimensions can amplify disturbances and affect service level (Christopher and Towill, 2002).

3.5.4 Customer Segmentation

D'Alessandro and Baveja (2000) show that customers can be segmented in order to prevent customers of little individual value to the company receiving costly services. Customers of larger size and importance receive a higher service level, which in turn put demands on the supply chain with regards to lead-times, availability, flexibility and stability. In fact, the customer of the product should be considered when segmenting products, in order to not hurt relations or lose important business.

D'Alessandro and Baveja (2000) further describe the case of Rohm and Haas's segmentation of their supply chain. Initially, problems were experienced with having one supply chain for all products, and moreover giving the same service to all customers. By segmenting products, they were able to create supply chain strategies for products based on the characteristics of the demand of the product. D'Alessandro and Baveja (2000) created a matrix, with volume and variability as dimensions, which could be used to visualise the product's demand characteristics and be used as a basis for supply chain segmentation. This matrix is presented in Figure 3.5.2.

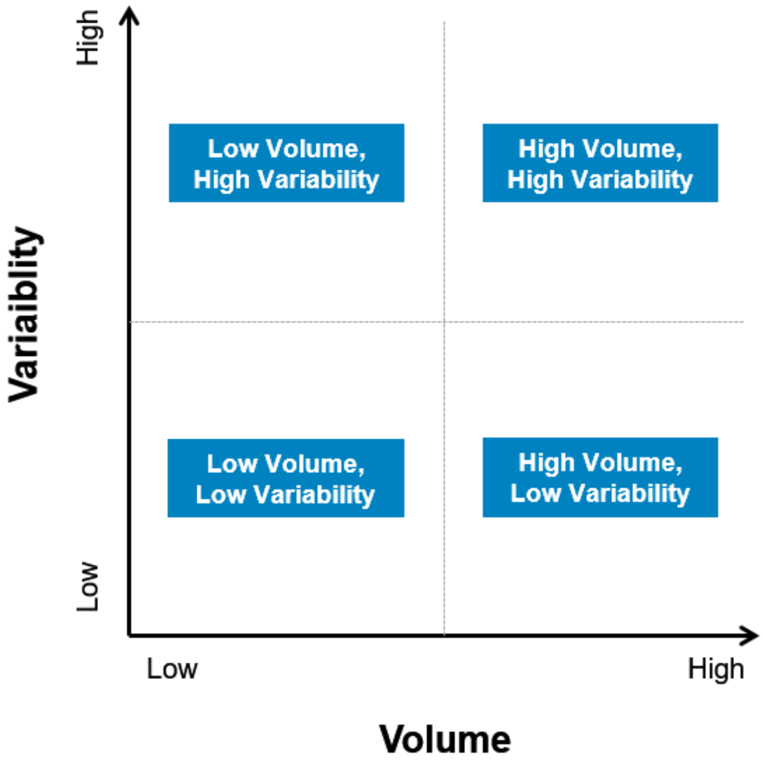


Figure 3.5.2: The matrix used by D'Alessandro and Baveja (2000) for segmentation.

The use of this tool as a basis for product segmentation and supply chain improvement led to a leaner organisation, increased production capacity, and millions of dollars in savings for D'Alessandro and Baveja (2000).

3.5.5 Strategy Groups

The segmentation of products should be the basis for the chosen production strategy. The production strategy should take product specifics and characteristics in account in order to segment products in such a way that supply chain performance is optimised (Jin and Gilligan, 2014).

A *Make to Order (MTO)* strategy is a strategy where no stock is kept for the material, basically turning all orders into backlog. For non MTO-products, some material is being kept in stock. (Economopoulos and Kouikoglou, 2011).

Sahin and Robinson (2005) investigated the implications of the upstream dependency for MTO products and concluded that the supply of components needed to manufacture MTO materials are often highly erratic and dependent on relationships between the supplier and the customer. With information sharing, the characteristics of the MTO strategy products can be somewhat reduced.

3.6 Campaign Planning

Campaign planning is a production process commonly used where changeover times are notable (Grunow et al., 2002; Susarla and Karimi, 2011). It is important to understand the theoretical principle, as well as its implications, to understand the production in the chemical industry, why this section will introduce the subject in greater detail.

3.6.1 Campaign Planning in the Chemical Industry

The production process in the chemical industry differs from many other industries; multi-purpose equipment usually serves to create several different materials with extensive set-up and cleaning in between materials. Often, *Changeover time*, or *Changeovers*, between batches of one material is less that that between batches of different materials. Consequently, *Campaign Planning* is common in the industry. By planning several consecutive batches of the same material, lead-times are cut significantly. *Ultimately, resulting from setup costs, several batches are usually produced together in the chemical processing industry*, although they may be meant for different customers or different packaging days (Grunow et al., 2002; Susarla and Karimi, 2011).

Utilising such an approach implicates a major trade-off to consider: an increase in working capital due to increasing inventory, and the reduction of changeover for which the approach is often used. Actually, long campaigns (rotations of productions) tend to increase working capital, and unnecessarily long campaigns will furthermore hamper flexibility. Meanwhile, shorter campaigns lead to an increase in changeover time, and thereby decrease in overall equipment efficiency (Susarla and Karimi, 2011).

When considering campaign planning, companies should consider their capacity. With finite capacity, the lot size has a major influence on production lead-times. As a result, one should not forget lead-times, as such a limitation could increase costs significantly, increase actual lead-times, while also increasing inventory (Susarla and Karimi, 2011).

A fully predetermined cyclical production plan may not be optimal, as demand is expected to vary over time for many products. Consequently, solving the production planning problem is highly complex and of mathematical character; often, linear programming is used, where varying demand requires rerunning the model regularly (Grunow et al., 2002). It is important that plans are reviewed regularly so that changes in circumstances and situation are accounted for and run through several instances (Susarla and Karimi, 2011).

3.6.2 Campaign Planning with Substantial Changeover Times

Planning production for materials with substantial changeover times, and/or where production order influences the production capacity, is a difficult problem to solve optimally. The general problem can be described as minimising the total changeover time, whilst maintaining flexibility in the system and keeping working capital low. Adding complexity to the general problem is a changing production mix, as it mathematically requires a new solution for every time period. While many lot sizing problems are solved using *Economic Production Order Quantities*, which allow for low inventory while enough material is produced to satisfy a given demand, such approaches work poorly with long changeover times, as the major overall cost becomes equipment downtime (Dionne and Kempf, 2011; Noblesse et al., 2014).

Dionne and Kempf (2011) describe a ”vicious cycle” of poor production planning, which can often be found where setup times are substantial. In production, the optimal production period of one material may be long enough to make the production of other materials suffer. As a result, planners may shorten the production periods to allow production of several materials, ultimately increasing changeover times. With less machine time available, lots become gradually smaller, leading to additional adjustments and reductions of production times. Ultimately, a cycle is created where lots become smaller and where production times are decreasing. As more time is spent on production setup, rather than actual production, the overall output is decreasing rapidly (Dionne and Kempf, 2011). The vicious cycle is visualised in Figure 3.6.1.

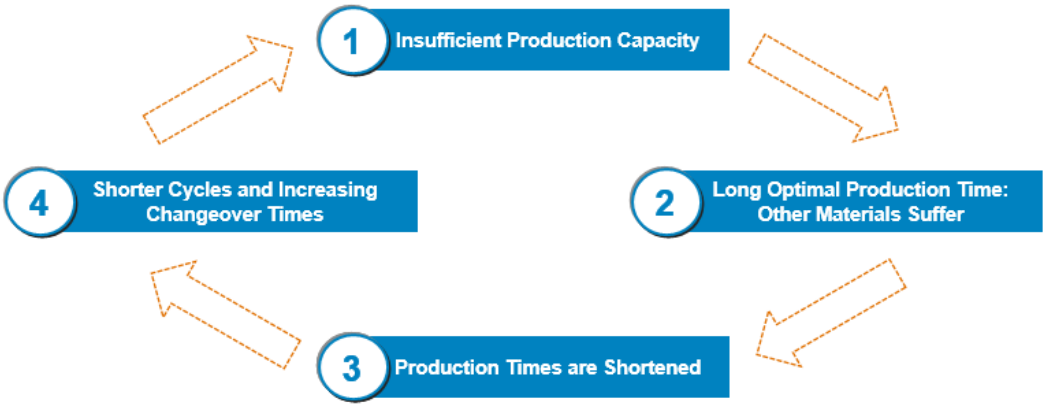


Figure 3.6.1: The vicious cycle of poor production planning as described by Dionne and Kempf (2011), illustrating how insufficient production capacity can lead to a decrease in production capacity.

3.7 Cyclic Production Scheduling

Cyclic Production Scheduling is a common approach in manufacturing industries where several products are produced at one workcentre, and where changeover times are significant; it is the implementation of a standardised production cycle in order to produce roughly the same materials each cycle, increasing efficiency, reliability and output (Schmidt et al., 2001; Ashayeri et al., 2006; Che et al., 2010; Schonberger, 1996; Olhager, 2016b). Cyclic production provides ideas concerning how production can be organised, why it is presented in greater detail in this section.

According to Ashayeri et al. (2006) and Olhager (2016b), *Cyclic Production Scheduling* is effective when producing low value, high volume products. By determining a fixed production cycle period and producing material in an optimal, or close to optimal sequence, the production output can increase.

3.7.1 Implementing Cyclic Production Scheduling

Literature describes both mathematical optimisation strategies (see Che et al. (2010)), and strategies of more qualitative character (see Ashayeri et al. (2006), Schmidt et al. (2001), and Schonberger (1996)), to implement cyclic production strategies. Ashayeri et al. (2006) describe how all materials need be produced in each production cycle, where Schonberger (1996) instead mean that all materials with sufficient demand should be included in the period. If capacity is constrained, segmenting could determine what products should be produced (Olhager, 2016b).

For the organisation, cyclic production represents a change from reactive to proactive planning (Schonberger, 1996). Such planning, according to Hayes et al. (1988), will make production more reliable, where it decreases unexpected downtime in production.

When operating under highly uncertain demand, a set schedule should not be implemented. In such cases, companies can instead choose to implement a *Regularised Schedule*, which allows reaping benefits from cyclic planning, although a standard cycle cannot be fully implemented. Schonberger (1997) suggests a model where some products with sufficient demand are scheduled to be produced two days every week, while other materials are produced on the remaining days. Thereby, some materials could be produced less frequently, but regularly. This model would furthermore allow certain flexibility in both the planning process and the production schedule.

Olhager (2016b) presents a cyclic production strategy for Coca Cola that used an existing product ABC-segmentation as a basis for production scheduling. Based on a lead-time analysis aiming at optimising production sequences, a cyclic production strategy was implemented. The schedule is presented in Figure 3.7.1

Figure 3.7.1: An example of a cyclic production schedule at Coca Cola with a total period of four weeks, as presented by Olhager (2016b). Illustrated, and thereby modified, by the authors.

3.7.2 Resulting Production Performance

Schmidt et al. (2001) illustrate how cyclic production scheduling can significantly increase the production capacity for an aluminium manufacturer with make to order production; the implementation increased output capacity with 20 percent. Similarly, Ashayeri et al. (2006) present a case where cyclic production had significant positive impact on production output, as well as inventory performance. In the case of Olhager (2016b), production output was increased by five percent, with maintained or increased service level for all products. In addition, working capital did not increase.

3.7.3 Capacity Planning

As described previously, many MRP-systems, used to conduct production planning by manufacturing firms, assume infinite capacity. Resulting, backlog appears when the system is running constrained (Milne et al., 2015; SAP AG, 2001; Snapp, 2013). This underlying assumption, unconstrained capacity, is not usually a substantial problem when most workcentres are operating below their maximal capacity. However, when workcentres are operating close, or at, maximal capacity, the unconstrained plan needs to be revised. Thereby, overall overall efficiency and effectiveness of the planning decreases (Snapp, 2013). Milne et al. (2015) argues that suitable integration of capacity planning in such a system will increase its efficiency. Samaranayake (2013) agrees, and emphasises the importance of using a holistic approach in order to address invisibilities in planning, exampli gratia from overloaded workcentres.

In order to allow for effective planning in the long term, trustworthy information about future demand is required (Samaranayake, 2013; Dionne and Kempf, 2011). The capacity planning aims at helping organisations identify their production capabilities, and examine how they will cope with future demand (Haider et al., 2015); capacity planning will let firms adjust production strategies to meet future demand without being wasteful, having too much excess capacity, or not having enough capacity. Ultimately, there is a cost to having underutilised capabilities. However, companies wish for certain under-utilisation, as it allows for flexible production with the possibility to absorb sudden changes in demand or production capabilities (Chen et al., 2009). By adjusting the overall production capacity, the problem of the MRP-system performing an unconstrained planning in a constrained environment can be avoided, simply by making the environment unconstrained. By adjusting the capacity, the efficiency and effectiveness of the production planning can be increased significantly (Snapp, 2013).

Three Tiers of Capacity Planning

According to Chen et al. (2009), there are three tiers related to capacity planning. The first tier, *Tier 0*, is the long term tier focusing on yearly resource requirements, plants, divisions and technology for new and existing product lines. In detail, four categories are included: (1) plant location and capacity, (2) major supplier plans, (3) production technology, and (4) operations modes and production methods.

The second tier, *Tier 1*, is the mid term tier focusing on existing plants and divisions and workcentre level. It contains six categories of decisions: (1) labour employment level, (2) inventory policy, (3) utility requirements, and (4) facility modifications, (5) outsourcing, and (6) major supplier contracts.

The final tier, *Tier 2*, is the short term tier focusing on setting the daily and weekly production plan per workcentre. Decisions in this tier are of operational character, deciding inter alia how material should be produced, how monitoring of performance should be conducted, and how general production scheduling ought to be conducted.

The tiers are summarised in Table 3.7.1 below.

Tier	Horizon	Decisions
0	Long term	Production location, major supplier integration, technology, and operation methods
1	Mid term	Employment level, inventory policy, utility requirements, facility modifications, outsourcing and major supplier contracts
2	Short term	Operations planning on a daily and weekly level

Table 3.7.1: The levels of capacity planning as described by Chen et al. (2009), with their respective time frame and related decisions.

According to Chen et al. (2009), it is easier to do changes in higher tiers. However, it is changes in the first two tiers that have significant impact on production capacity. As it is costly and timely to conduct changes to the lower tiers, it is generally of high importance to thoroughly investigate and evaluate any effects of such changes.

Chapter 4

Company Description

4.1 ChemCo Described

This section describes ChemCo's business from a holistic standpoint for the reader to further understand the business, but also the thesis' scope. Data is gathered from internal and official external documents.

4.1.1 Geographical Structure

ChemCo has its base and headquarters in the northern US. Here, most of the global management team has their base, but the office also works as the main office for US business, including finance, customer service, the supply chain department and other key functions. Management positions of more operational character is situated closer to plants, with plant managers, operation managers and many planners being active at the plant where most of their materials are located.

Plants are scattered around the world, some countries having several plants.

The Americas There are three American manufacturing plants: Plant A and Plant B in the northern and southern US, and Plant C in Mexico. Moreover, Plant A includes a research- and development facility, developing chemicals for the pharmaceutical, laboratory and electronic materials markets.

This study focuses on the Salts business, which is produced at Plant A, close to the headquarters.

Europe There are two manufacturing plants in Europe: Plant D and Plant E. Plant D includes much of the European administration, with several managers. During early 2016, much of the Plant D business was closed down or transferred to Plant E: a direct result of a management decision to shut down the first-named early 2017. Plan D therefore focuses solely on a few key assets, and on supporting the transfer to, and integration of, the Plant E.

Asia ChemCo has three main plants across southern Asia. In addition, smaller plants exist across all of Asia, focusing on cross-docking, storage or preparation. In addition, ChemCo has several research facilities in close location to their main plants.

4.1.2 Internal Structure

The by far largest portion of the company is represented by the COO, who has 14 managers directly under him, all representing substantial teams at ChemCo: ranging from sales, and customer service to quality control, line directors and the *Supply Chain Director*. On lower levels, a vast range of middle managers is represented: from lab managers, and production managers, to engineering officers and distribution managers.

Importantly, many key functions in the company are divided according to material characteristics: either (1) commercial or (2) production characteristics. For (1), the *Strategic Business Units (SBUs)* are used. For (2), organisation is based on internal production; one example being *Salts*, which this report will focus on. Material categorisation and division, with a focus on Salts, is explained later in this report.

Cross-area Utilisation

Since several years ago, ChemCo has continuously been subject to large transformations, with the change from Plant D to Plant E being a key focus area as of mid-year 2016. Such a focus require cross-country resources and knowledge, something ChemCo has utilised not only by taking into consideration best-practices of other countries, but also in how managers are used across regions. One such example is the *Supply Chain Director*, Johan L., company supervisor of this thesis, who is working not only at all three US locations, but also in both European locations.

Organisationally, the company have key management positions in all continents where applicable. Each region has its own management, exampli gratia a *Vice President of Sales*, a *Vice President of Production* etcetera, answering to the global function: the *Chief Operation Officer* in the example of the *Vice President of Production.* Such managers may, or may not, communicate frequently, depending on the nature of the business; some regions may share key customers, while others in practice work as independent companies.

4.2 ChemCo's Supply Chain

This section will present ChemCo's supply chain, starting on a synoptic level, presenting the basics of the structure. Data is gathered from internal documents, dialogue with managers in the scope of the thesis, and an understanding which has developed throughout the project.

4.2.1 Supplier Contact and Management

ChemCo sources its ingoing materials from vendors worldwide, not always taking geographical distance into consideration. Certain production requires material produced in other parts of the world; examples cannot be given due to the highly confidential nature of ChemCo's business and processes.

Ingoing materials, internally and in the rest of this report generalised as *"raw materials"* or *"raws"*, are either actual raw materials or processed materials. They can be specific to a particular product, with unique specifications and/or quality requirements. In such cases, the qualification is based on end-customer needs. Materials are shipped to each respective production plant, and stored in warehouses before production, a process in which they often get quality controlled according to specifications.

4.2.2 Production

Close to all production is planned on a per-plant basis, although materials may share resources, such as production equipment.

There are exceptions to the rule, where exampli gratia one material group is produced in both US facilities, depending on current constraints and demand; production equipment used is similar, and materials are qualified to run on several locations.

Production includes several closely linked functions, including everything from quality control to engineering and supervisors.

Cross-plant Operations

As for production and supply, plants have certain focuses for materials, with exempli gratia Plant A producing Salts that are also stored in, and transferred from, Plant B. Although much material is produced close to key customers, materials can be transferred between plants. Exemplifying this are European plants stock-keeping material produced in both Plant A and Plant B, in order to help meet European demand. In addition, materials can also be sent cross-continental directly, without going through ChemCo's own plants.

Production Flexibility

Due to the nature of the high quality chemicals sold by ChemCo, production gets complicated. The materials are often closely monitored by customers; subsequently, many materials are thereby specified in great details with customers putting emphasis not only on the process, but also on quality control, including granularity of quality assurance. Ultimately, this is closely related to production, as materials may not be arbitrarily transferred between resources, and moreover, plants. Consequently, capacity and production planning is a complex process due to the need of flexibility, comparatively to materials of more commodity-like characteristics which seemingly can be transferred between resources to avoid constraints. Additionally, many production processes may not be altered without customer approval, adding another layer of complexity.

Changing production processes can be a result of (1) *Engineering Changes* or (2) *Transfers*. Engineering changes to production may or may not require customer approval, depending on the degree to which it could impact product quality. Some changes, of less radical nature, solely requires customer notifications. As for transfers, these can either be between (a) resources or (b) plants, including cross-country transfers.

For several materials, including Salts, both types of transfers require customer approval through a qualification process. Thereby, materials are bound to be produced at one resource, unless having gone through the full process taking many months to conduct. As a result, planning of key materials is characterised by a lack of flexibility, showing in inter alia capacity fulfilment and production setup - including, but not limited to, lot sizes and lead-times.

4.2.3 Distribution and Warehousing

As for logistics, ChemCo utilises a strategy combining internal resources with third party providers. In example, the US business store materials in internal warehouses on plant-grounds, while the European business, as part of the transformation, instead use a third party provider for storage of finished goods. However, raw materials, materials in production and materials waiting to be shipped, are all stored at the plant in order to provide flexibility.

As for shipments, the general rule of ChemCo is to utilise third party providers, depending on the region or customer preferences. This means that several logistics providers are used daily around the globe, providing everything from truck transportation to intercontinental shipping or even air-freight. Such an approach to logistics does provide certain flexibility, most notably for different customer needs and preferences.

4.2.4 Customer Service and Sales

ChemCo manages customers in two key areas: (1) sales and (2) customer service. These are presented in greater details below.

Sales

ChemCo has a department focusing on sales, represented by the *EVP of Sales.* The Sales-team focuses on travelling to, and visiting, customers. Relatedly, ChemCo has chosen not to have an in-house sales team.

For customers that are recurring and/or of substantial size, ChemCo tries to gather forecasts in order to plan for greater customer satisfaction. Such data is gathered on continuous basis, or whenever customers are planning new changes in their demand-pattern, which can be the result of new production, products or services. This data is then integrated into the forecast used by ChemCo for production planning.

Customer Service

ChemCo has a department for customer service in each of the regions, all answering to the *Director of Customer Service.* Service is available on a two shift-operation basis from the US, with the company aiming at being available to customers during the day. The function is available in the respective region-offices, and work in-house.

Customer service handles everything related to questions about products, including complaints, but also help putting in orders.

4.3 Measuring Supply Chain Performance

This section presents ChemCo's methodology of measuring supply chain performance. These are used to evaluate projects, including results from this thesis. Data is gathered from internal documents, and dialogue with managers in the scope of the thesis.

As for control, cadence and government, the organisation is largely built in layers, with key organisational governance being current on top-management level. Every continent has its own governance on lower level, ranging from yearly reviews and controls to daily control-meetings for inventory, production, quality control, sales and planning.

4.3.1 Continuous Reviews

Several meetings are carried out a continuous basis, some daily, others weekly. Key meetings are presented in brief below.

Control Tower

Frequency: Weekly and daily
Attended by: Planners, Customer Service, Quality Control, Distribution
Goal: The control tower, called SteerCo, consists of both daily huddles and weekly meetings, presented in detail below. Ultimately, it aims at tracking everyday operations performance.

Supply Planning

Frequency: Semiweekly
Attended by: Production, Planning
Goal: The supply planning goes through production and planning in great detail with the goal to: (1) ensure feasibility through taking both perspectives into account and to (2) address the most problematic orders and materials.

Supply Review

Frequency: Monthly
Attended by: Production Managers, Operations Managers, Supply Chain Team
Goal: The supply review aims at continuously analysing supply, including production, planning, and capacity.

Demand Review

Frequency: Monthly
Attended by: Demand Team, Product Managers, Commercial
Goal: The demand review aims at analysing and improving forecasted demand. ChemCo's forecast is carefully walked through, looking at top deviators, but also on new demand-patterns provided by customers.

Sales Inventory Operations Planning

Frequency: Monthly
Attended by: Production Managers, Operations Managers, Supply Chain Team, Distribution Centers, Commercial

Goal: The SI&OP meeting is most strategic among the continuous supply chain meetings, aiming at discussing key questions and issues related to supply chain. The meeting is highly action-oriented, focusing on decision around sales, investments, shifts and fixes to problems.

Planning and Scheduling Cadence

The weekly *SteerCo*, or *Control Tower*, constitutes the cadence structure at the lowest level of ChemCo's supply chain: planning and scheduling production. This meetings aim at providing transparency concerning current performance, but also about problems and unanticipated happenings, such as problematic orders, backlog items, or failed tests. The meetings included are described in brief detail below:

Weekly Health Review
Attended by: Customer Service *Goal:* Looks into key backlog items, orders at risk, and inventory health.

Weekly Supply Review
Attended by: Planners
Goal: Looks into key backlog items, short-term capacity, with a tool called "HeatMap", key scheduling items that need expedition, and the inventory health.

Daily Huddles
Attended by: Planners, Quality Control Personnel, and Distribution Centers
Goal: Daily discussions with key supply chain functions regarding backlog, inventory health, OTIF-performance and weekly distribution.

4.3.2 Key Performance Indicators

In order to increase transparency and measure performance uniformly, ChemCo has introduced several *Key Performance Indicators (KPIs)* for the supply chain. These aim at measuring the most important aspects, ranging from planning to inventory. Moreover, the KPIs are used as a basis not only for the meetings carried out, but also as the basis for bonuses - directly measuring the performance of planners.

There are several KPIs used, the most important ones being presented below.

OTIF
On Time, In Full deliveries. Measures ChemCo's capability to fully deliver orders to customer within the requested time frame.

Manufacturing and Distribution Backlog
Value of orders late according to schedule: all backorders. Measures how production and logistics is keeping to schedule: backlog means that items are not fully processed, although they should have been according to plan.

Inventory Health
Inventory compared to plan. Inventory is measured both based on asset type and per plant regarding their levels in comparison to optimal ones: namely inventory over and under their set stock levels.

Slow and Non-moving Inventory

Inventory with low activity. Inventory that is not moving, often meaning being sold or being used for production, is tracked in order to track when unnecessary inventory is being built.

At Risk Orders

Orders requiring action to not become backorders. Some orders will add up to the backlog if they are not handled, implicating that action is needed.

Exception Orders

Unexpected orders with high impact. Incoming orders from customers that are largely unanticipated when it comes to size or complexity. One example causing this could be unexpected demand as a result of changed customer priorities, therefore not integrated in the forecast, and hence, the order planning. These orders are controlled manually, and are postponed if they hamper planned production, which customers get informed about.

In addition, two key tools are used to track operational performance, although they are not really KPIs.

Capacity Heatmap

Capacity constraints and under-utilisation. A tool is used to compare current resource utilisation in comparison to a rolling six month average, illustrating both under- and over-utilisation.

Strategic Capacity Planning

Capacity constraints and under-utilisation. This tool was created by the thesis authors outside of the scope for the thesis. It simulates long-term capacity planning at ChemCo, and is hence used to plan production long-term, and to evaluate transfers, shift-changes and investments.

Although all of these are clearly communicated and analysed, ChemCo has chosen to focus efforts on selected ones - why they are monitored in closer detail, and also analysed on meetings of more strategic character. The prioritisation follows a heuristic:

1. OTIF
2. Backlog
3. Inventory Health

Chapter 5

Production Description

5.1 Material Categorisation

This section presents how ChemCo groups their materials, important to understand the production and organisational structure. Data is gathered from internal documents, and dialogue with planners, engineering and managers in the scope of the thesis.

Materials produced at ChemCo are divided into *Strategic Business Units*, *Production Categories* and *Production Strategies*. The segmentation is three-dimensional, segmenting from a (1) commercial perspective, (2) production perspective, and (3) supply chain perspective. Such a three-dimensional type of segmenting is visualised in Figure 5.1.1.

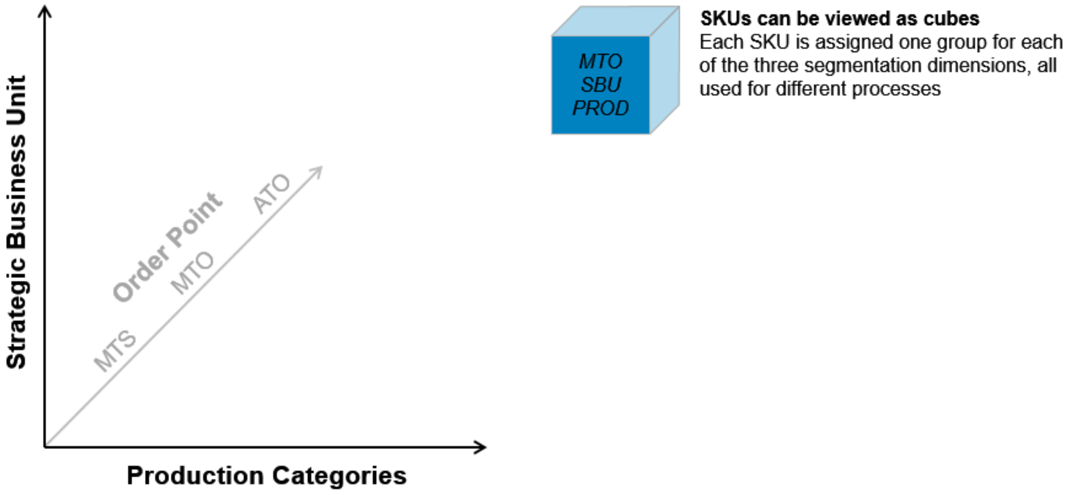


Figure 5.1.1: Each SKU have assigned an SBU, a production category, and a production strategy.

Data is gathered from internal documents, dialogue with managers in the scope of the thesis, and an understanding which has developed throughout the project.

5.1.1 Strategic Business Units

Materials produced at ChemCo are divided into four strategic business units. Such a break-down exists mainly from a commercial perspective, dividing materials by the basis of markets where they have their main application. As mentioned previously, customers overall are within academia, the electronic industry, laboratory industries and pharma. These areas do not reflect actual business units, which are not presented due to confidentiality reasons.

5.1.2 Production Categories

Materials produced at ChemCo are also divided into production categories. Such categories describe key production characteristics of materials. Often, this segmentation is the basis for how materials are planned and produced, as certain synergy advantages can be realised. ChemCo has chosen eight key categories, where the thesis focusing on *Salts*. ChemCo also produces materials such as solvents, solutions and different powders. Categories are not presented due to confidentiality reasons.

5.1.3 Production Strategies

The final of the three segmentation is the one focusing on the supply chain perspective: describing the order point of the product. Three such categories exist: *Make to Order (MTO)*, *Assemble to Order (ATO)*, and *Made to Stock (MTS)*. This strategy influences several material factors, including if stock should be kept or not. Moreover, the strategy greatly influences customer lead-times, as it ultimately describes which sub-processes are included in the total production process, as explained by Figure 5.1.2.

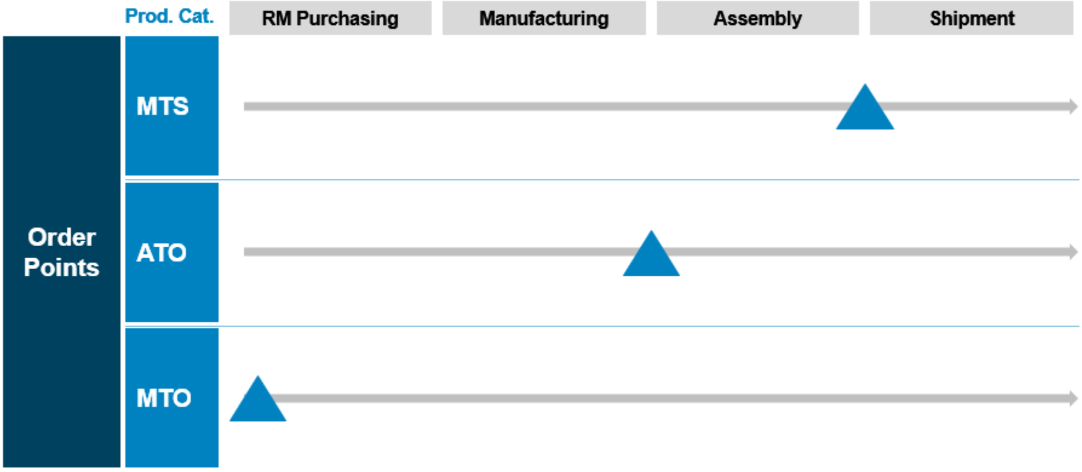


Figure 5.1.2: The strategies explain where the order point is current: meaning which sub-processes comprise the total process.

Make to Order

MTO products are not kept in stock, and neither are their component's raw materials; when an order for an MTO is placed, raw materials are ordered. MTOs generally have the longest lead-times, as they include procurement, quality testing, planning, production, packaging, and shipment. The MTO strategy is relatively small at ChemCo, containing only 18 percent of the SKUs. As a rule, the MTO group at ChemCo should focus on materials with low volume and/or inconsistent demand.

The MTO strategy was implemented at ChemCo to be able to offer a broad product portfolio without increasing the amount of SKUs in stock, and therefore avoid unnecessary increase in working capital.

Assemble to Order

ATO products are not kept in stock, but have components that are stocked according to a forecast. Such components can be either intermediate materials or raw materials. At ChemCo, 17 percent of materials are ATOs. The lead-times of ATOs are generally shorter than those for MTOs, as purchasing and production of some intermediate materials are separate. Generally, SKUs in this group are produced in high quantities, but are later packaged in several different containers. This allows for a high flexibility and a wide product portfolio as a single manufactured batch can become 20 different SKUs depending on how it is packaged.

The ATO strategy was implemented at ChemCo to be able to offer a broad portfolio of product variations without increasing the amount of SKUs in stock or the amount of materials manufactured, and therefore avoid unnecessary increase in working capital.

Make to Stock

MTS products are available for delivery when an order is placed; unless it is unexpectedly large, so called *Exception Orders*. As materials are kept in stock, customer lead-times are kept short: two days excluding shipping within the US. MTS production is planned towards ideal stock levels which in turn are set using forecasted demand: when stock-levels get low, production is planned in order to replenish stock. Most materials at ChemCo are MTSs, representing 65 percent of SKUs.

5.2 Salts Production

This section gives an overview of the Salts supply chain, describing the process from a customer order to the final delivery. This process needs to be understood in order to develop a technique for the production category: including understanding the current situation, constraints to consider, and what possibilities exist. Data in this segment is based on dialogue with engineers and managers, as well as analysis of ERP-data.

At ChemCo, ”manufacturing” and ”production” are not used interchangeably. ”Manufacturing”, or ”make” for short, denotes the creation of the finished good from raw materials, but excludes packaging. ”Production” includes both the manufacturing and the packaging of the material. The two words will hereafter be used accordingly.

For clarity, the term ”packaging” will hereafter refer to the activity of placing the chemical in the container it will be delivered in, exempli gratia a 19 liter plastic bucket. ”Packing” will refer to the packing of the SKUs on a truck in order to ship them.

The terms used are visualised in Figure 5.2.1.

Figure 5.2.1: A figure clarifying the difference between *Manufacturing* and *Production*.

Salts are produced at five workcentres, denoted WC1-5. Each workcentre can produce one type of salt at a time and its capacity depends on which salt is being produced. The workcentres are all located at Plant A. Production capacity can further be adjusted by modifying the shift structure of the workforce. Salts are normally running at a 24/7 shift structure, implying that there is no extra capacity to be gained from modifying the shift structure. If the workcentre is running over capacity, one or several shifts could be removed.

The overall process, from placed orders to shipped material, is presented in Figure 5.2.2. The steps of this value chain will be presented in the following subsections.

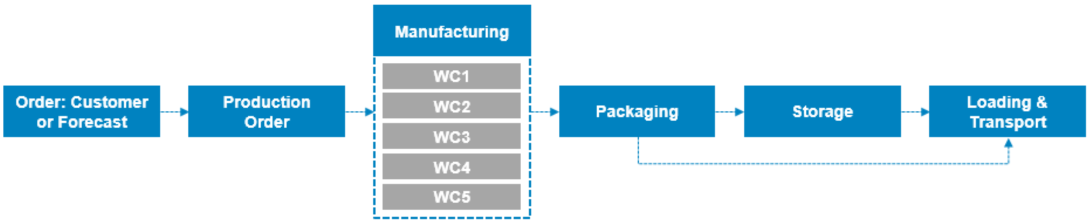


Figure 5.2.2: A flowchart visualising the process of supplying product to the customer, from the customer placing an order to the loading of the material on a truck at the distribution center.

5.2.1 Customer Orders and Forecasted Orders

The first step in the production chain consists of customer demand being converted into orders in the system. There are two types of orders: *Customer Orders*, which are actual orders from customers, and *Forecasted Orders*, which are simulated based on customer demand. This demand becomes the basis for production orders.

This topic is covered thoroughly in Section 5.3.

5.2.2 Production Orders

Production Orders schedule the production needed for customer demand. There are two types of production orders: *Planned orders* and *Process orders*. Planned orders are to be produced, where process orders are the basis for actual production.

Depending on production strategy, production orders are formed differently. For MTS items, most customer orders do not affect the volume produced, as production is generally controlled by target stock values and forecasted demand. For ATO and MTO materials, each customer order will be converted into a production order. The one exception being if several orders are placed for the same material, in which case they are consolidated by the system.

This topic is also covered thoroughly in Section 5.3.

5.2.3 The Salts Manufacturing Process

All workcentres which produce Salts follow the same principles, although having different dimensions, equipment and capacity. The manufacturing can be described in three steps: *Mixing*, *Agitation* and *Evaporation*. After the three steps are completed, the material is packaged, and thereafter shipped or put in stock. The manufacturing process is the main bottleneck in the value chain, why it is described in great detail.

Mixing

The first step in the manufacturing process is the mixing of raw materials. Generally, two or three materials are put in water in order for them to dissolve. Two dimensions in this step greatly affect the quality of the finished good: the quality of the raw materials used and how accurately the quantity of material put in is measured.

- The quality of the ingoing raw materials is meticulously tested by quality control. The water used, *WFI-water*, is produced locally and tested daily. This water is free from impurities, guaranteeing the quality of the end material.
- In order to produce materials of the right grade, concentration and quality, the recipe needs to be followed carefully. Even when mixing several tonnes of material, raw materials are measured to an accuracy of a 10th of a pound. This is generally done with high accuracy industrial scales.

Materials are weighed and added to a large tank that have been filled with the correct amount of WFI-water. Material are added manually by an operator, who follows a very detailed ”process recipe” designed by the process engineer. Important points of time are noted in the recipe and in a logbook. Some assisting equipment exists in order to speed up the process and make the work more ergonomic. Most of the time spent in the mixing phase is spent loading material.

Agitation

The agitation is the second step of the process. In the this phase, material is recirculated in the tank for several hours. The purpose of the agitation is to ensure that all materials dissolve properly and that the blend is homogeneous - a time-consuming process. To ensure that materials fully dissolve, and to reduce the time somewhat, the tank is heated. The process is occasionally checked by an operator, although not requiring constant attention.

Once the material is agitated, a sample is taken to the quality control lab for analysis. This analysis aims at ensuring the quality of the solution, including concentration. Potential skewness can be compensated for, should the test fail, inter alia by adjusting concentration, or allowing for further agitation.

Evaporation

The final manufacturing step describes the evaporation. This is the phase in which the salt solution becomes a dry material. The agitated and tested solution is put in a special ”pool”, where it is allowed to evaporate with the elp of furnaces. The process takes several hours, and is checked occasionally by operators. Once evaporation is completed, a final sample is taken to quality control in order to ensure conclusive quality, before the finished good is cleared for packaging.

Manufacturing Changeover Times

There are two types of changeovers in the Salts manufacturing process: (1) *Inter-Batch Changeover* and (2) *Inter-Material Changeover*. The inter-batch changeover is quicker than the inter-material changeover. This implies synergies from producing several batches of the same material in sequence; as trace elements of the previously manufactured material wont harm the purity of the new batch of the same material, cleaning time can be reduced.

When switching production from one material to another, the machinery needs to be cleaned. As ChemCo produces high grade chemicals, the process is rigorous in order to make sure that nothing of the previous material is left in the machinery and can contaminate the new material. The cleanouts are generally performed by "flushing" the equipment with water or by using a stronger solvent and thereafter water. The cleanouts do not require much active work by the equipment operators but result in considerable downtime for the equipment. Several days of running solvents and water through the equipment are necessary to reach the desired purity.

After a cleanout has been performed, a test is performed by quality control in order to make sure that the cleanout was successful - meaning that no trace material is left. This control is carried out at a particles-per-billion level to meet quality specifications.

General changeover times on a workcentre level, including cleanout and the lab testing of the final flush sample, are illustrated in Table 5.2.1.

Asset	Inter-Material Changeover time
WC1	3 days
WC2	2 days
WC3	3 days
WC4	2 days
WC5	2 days

Table 5.2.1: General inter-material changeover times at the five workcentres, shown for 24/7 production.

Finally, after the test, the first finished containers of a material is discarded to further guarantee purity, and to eliminate potential quality variance that may exist in the first container in a batch.

The rigorous cleanout, together with lab tests, are what differentiates ChemCo from competitors. SIOP Manager, also the PS, argues that these tests and cleanouts are where ChemCo's superior value is created: the processes result in high margins on materials sold. However, they are also the foundation for long changeover times.

Reducing Changeovers It is possible to lower the inter-material changeover time by planning the transitions of material. This is done by the production planners. As an example, the changeover time required between *Material A* and *Material B* is lower than the changeover between *Material A* and *Material C*. Reduced cleanouts are presented in Table 5.2.2

Asset	From Material	To Material	Time
WC1	Material A	Material B	24 hours
WC2	Material A	Material B	24 hours
WC2	Material C	Material D	24 hours
WC3	Material E	Material F	36 hours

Table 5.2.2: These chemicals require reduced cleanouts and no lab testing when transitioning between them in production, significantly decreasing the changeover time.

Integrity of Changeover Data Changeover data presented is based on historical cleanout data from Plant A, further verified by the process engineer to ensure accuracy. The major risk to its integrity lies in faulty ERP-data, which is put in based on manual observation. However, such times have several occurrences, and the process engineer further described outliers in great detail during verification.

Production Capacities Production capacities for Salts are estimated statistically from historical batch sizes and production lead-times at each of the workcentres. Such data was extracted from the ERP system, where time stamps are entered manually. Start and end of production times are registered automatically. In general, manufacturing is the bottleneck of the process, with packaging and lab working unconstrained even during heavy loads. For this reason, the complete production capacity of a workcentre can be calculated by knowing the manufacturing capacity: manufacturing capacities are equivalent with production capacities.

To illustrate capacities, it can be mentioned that WC1 Salts products range from around 20 000 to 30 000 pounds per week. A list of capacities on SKU-level is not presented due to confidentiality reasons. The different workcentres have either one or two lines for producing Salts. The number of lines can be seen in Table 5.2.3. In general, two lines close to doubles capacity.

Asset	Number of Lines
WC1	1
WC2	1
WC3	1
WC4	2
WC5	1

Table 5.2.3: The number of lines for producing material at each workcentre.

Integrity of Capacity Data As the capacity data is based on manual observations, several sources of error could influence or bias the data. Generally, time stamps are rounded off to the nearest five minutes by the operator, as explained by several operators. Although this is somewhat limiting the resolution of data, manufacturing is generally running over days, why the bias introduced by rounding should not compromise the quality of the analysis.

As for batch sizes, the data integrity is assumed high as batch sizes, without exceptions, are determined before the start of production and are generated by the ERP system. Moreover, planners review the generated sizes, adding to integrity. Manufacturing follows the plan generated by the system to make the correct amount of material. Finally, the total amount actually produced is reported, where differences were found of less than a tenth of a pound.

In addition, a few additional integrity questions were analysed. First, as for timing, the data was gathered for 2015 and 2016, where there were no major changes to the production process. Secondly, as for using the manufacturing capacity as the process capacity, drastic changes in manufacturing capacity could force packaging or the lab to run constrained. Should this happen, manufacturing capacities could not be used as production capacities, and the assumption would be rendered wrong. The process engineer did not believe that this would become a problem. Finally, to further confirm data quality, the process engineers reviewed calculations, as well as qualitatively analysed the times based on experience, without objection.

5.2.4 Packaging the Material

The packaging process mainly depends on the container in which the material is to be delivered. The finished material is moved from the pool into a large container from which it will then be packaged. The larger container is used to fill smaller containers, where the size of the smaller ones decides the number of operators needed. Container sizes vary greatly between SKUs; commonly, Salts are packaged in drums with 100 to 200 kg of material. Smaller containers include eight kg plastic buckets. The larger drums are filled with a vacuum hose, while smaller containers are filled manually.

The packaging process is rarely a bottleneck for production, as the packaging of any given amount of material generally is quicker than the production of the same amount of material. However, operators at the packaging station can be utilised somewhere else, leaving incentives to minimise the amount of time spent packaging anyway.

After the packaging is done, the material is moved to the finished goods storage or the shipment warehouse if it is supposed to ship instantly.

5.3 Salts Planning Process

This section aims to explain the production planning process at ChemCo. An understanding is needed to identify problems in the current process, to design a new technique, and to assess the impact such a technique could have on the efficiency and the effectiveness of production planning. Data in this segment is based on dialogue with planners, engineers and managers, the workshop conducted, but also field notes from working in close proximity to the process.

The planning process can be described as a three step model. Initially, a trigger in the form of an order starts the planning process, in the second step production is planned, and finally in the third step the plan is executed. The model is illustrated in Figure 5.3.1 below. This section will be constructed around this three link chain, describing each link of the chain in a subsection.

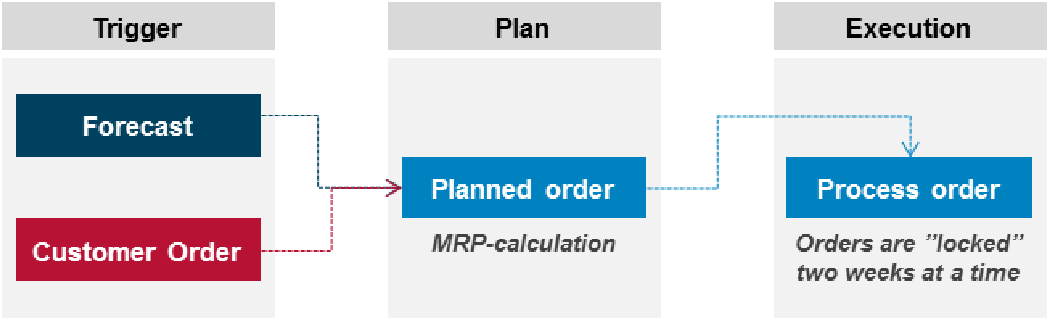


Figure 5.3.1: The three steps of the planning process with demand triggering an order, the planner planning production, and the plant executing the production plan.

The MRP system at ChemCo is conducting unconstrained planning. Capacities are not taken into account and the system plans more production than would be feasible, should the system be running constrained. Any load can be put on the available resources. Unconstrained planning is effective when the workcentres are running unconstrained. However, when demand is greater than production capacity, it is up to planners to level capacities in order to produce a feasible production plan.

5.3.1 The Trigger

All planned production at ChemCo stems from customer demand in one of two forms, also described previously. Depending on the product strategy, the base of planned production can be forecasted demand or direct customer orders. Planning based on demand-forecasting is indirect in nature, meaning that production is planned to meet inventory levels and not demand directly. Production for ATO/MTO-materials is direct and based on customer orders.

Trigger for MTS Materials

For MTS materials, customer demand needs to be forecasted in order to know how much material that should be in stock. For this task, there are two demand managers (DEO1/DEO2) who work full time with updating the forecasting model, talking with customers, and to provide the SIOP-functions with material for decision making.

The model is using statistics, where historical buying patterns are used to simulate future buying patterns. Mainly, it uses exponential smoothing, but further utilises time series to model reoccurring demand patterns.

In case there are strong indications that the demand for a material will deviate substantially from the forecast, overrides can be manually put in by the DEOs. These are used sparingly, as managers have experienced that overrides make the forecast less accurate. However, certain overrides are important, such as large customer orders, marketing pushes or significant customer growth.

Forecasted demand data is used to set target inventory levels, designed after a desired service level. At the time of writing, the service level target of ChemCo is 95%. These target inventory levels, together with current inventory levels, act as a trigger for production planning. Should the demand spike, more production is planned in order to compensate and to not run out of stock.

Trigger for ATO and MTO Materials

For ATO and MTO materials, all production is triggered by direct customer orders. When a customer places an order, the system will schedule production to fill the order.

Trigger for Ingoing Materials

For MTS and MTO materials, not all raw materials are kept in stock. This means that when production of an MTS or MTO is scheduled, purchasing orders are automatically placed for the raw materials needed. There is however one exception to this rule, where, for some MTS and MTO materials, certain raw materials are kept in stock as they are also raw materials for an ATO.

For an ATO material, all ingoing materials are kept on stock. These materials are purchased, or sometimes produced, on the basis of inventory levels. Once the inventory level gets low, new material is ordered in order to ensure constant availability. Hence, they are planned in the same way as an MTS, described above.

Redundant Inventory Build Up The unconstrained planning leads to redundant inventory build up of raw materials. As the system is creating impossible production plans, more raw- and packaging materials are requested than feasible. Consequently, only a fraction of the system generated production orders should actually be carried out, where ChemCo relies on planner experience and intra-company communication. In practice, this has not worked flawlessly and has lead to two main problems: first, ChemCo was close to run out of physical space due to raw materials building up, and second, the working capital consequently increased significantly. ChemCo is currently working with this problems, where all purchasing orders are screened by managers in the supply chain team to prevent unnecessary inventory build.

Inaccurate Delivery Times Purchasers in general feel that they cannot trust delivery times provided by suppliers, meaning that they add substantial buffer time to some orders to guarantee availability of material when it is due for production. This process is time-consuming as the purchaser has to evaluate the supplier's historic performance with no system support. The arbitrary buffers also increase inventory build.

5.3.2 Planning Production

There are two steps in the planning process: (1) the *Unconstrained Production Plan* created by the MRP system, and (2) the *Re-leveled Plan* by planners.

MRP Unconstrained Planning

The MRP system is run daily to schedule future production and issue purchasing orders. Depending on the strategy group of the material, adtes are calculated differently.

For MTS items, production as a *Planned Production Order* is scheduled for when all material have been delivered to the plant and all quality control have been performed on the purchased material. The system always schedules production as soon as possible in order to refill the stock.

For ATO items, the system schedules production in the form of a planned production order once an order is placed. If components are unavailable, it further triggers production of those components. The system plans the production based on system lead-times, where manual adjustments can be made to the purchasing order based on customer requirements, before the unconstrained planning us carried out.

For MTO items, once a customer order is placed, the system schedules purchasing of needed raw materials. Production is then scheduled as a planned production order based on the system lead-times.

Re-Levelled Planning

With the MRP-system running unconstrained, production in the form of planned production orders are scheduled with no concern for the plant production capacity. The result could be several production orders placed on the same day, although a single order takes two days to complete. In order to compensate for the system limitation, production planners are tasked with going through production orders to ensure that production managers get a feasible plan. In practice, levelling is done by moving orders forward and backward, so that demand is produced when capacity exists. The planner has to consider raw material and packaging availability, urgency of orders, capacities of workcentres, and synergies in scheduling certain SKUs in parallel or in sequence. Often, this is done in Excel, and without help from the system.

Manual planning is greatly aggravated in situations of considerable backlog, as there then are scheduled orders that are not yet produced. As the system plans all production in the next planning period, and the planner has nowhere to move production during substantial backlog, planners are in practice doing planning unaided.

The suggested plan is iterated with production engineers in order to ensure that it is doable and that all important factors have been taken into consideration.

Once the plan is set, the planner will re-enter the production orders in the system, now as *Process Orders*. These are to be considered the final production plan. The plan is frozen for 14 days in order provide a stable environment for actually planning and carrying out the production on shorter term. Functions related to production now have a 14 days plan to follow.

Lead-time Components

Lead-times can be split into two categories: (1) *Internal Lead-Times*, and (2) *External Lead-Times*. Internal lead-times are used internally to describe how long it takes to produce a material. Meanwhile, external lead-times are communicated to customers, and should thereby describe how long it should take before the customer can get a material once an order is placed. For MTO and ATO items, the internal and external lead-time is identical with exception for transportation. For MTSs, production time always require more time than the shipping - two days within the US.

The main drivers of the *Total Replenishing Lead-time (TRLT)*, normally describing the full internal lead-time, are *Delivery Time (PDT)*, *Quality Control Time (GRT, GRPT, or QC)* and *In-house Production Time* (here abbreviated as *IHP*).

Delivery Time PDT describes the time it should take from an order of a raw material is placed, until ChemCo has received tha material in its warehouse.

Quality Control Time GRT describes the time needed to quality-test materials. Often, production processes include several quality controls: (1) *Raw Material Testing*, (2) *In-Process Testing* and (3) *Finished Goods Testing*, where the second step in turn can consist of multiple rounds. Moreover, each one of these steps often include several tests, measuring different types of quality.

Production time IHP describes the time it takes ChemCo to produce a particular material. It should not only contain the actual processing time, but also the time spent inactive waiting for available capacity.

Lead-times and Strategy groups

Depending on the strategy group of a material, different drivers are included in the TRLT, illustrated in Figure 5.3.2.

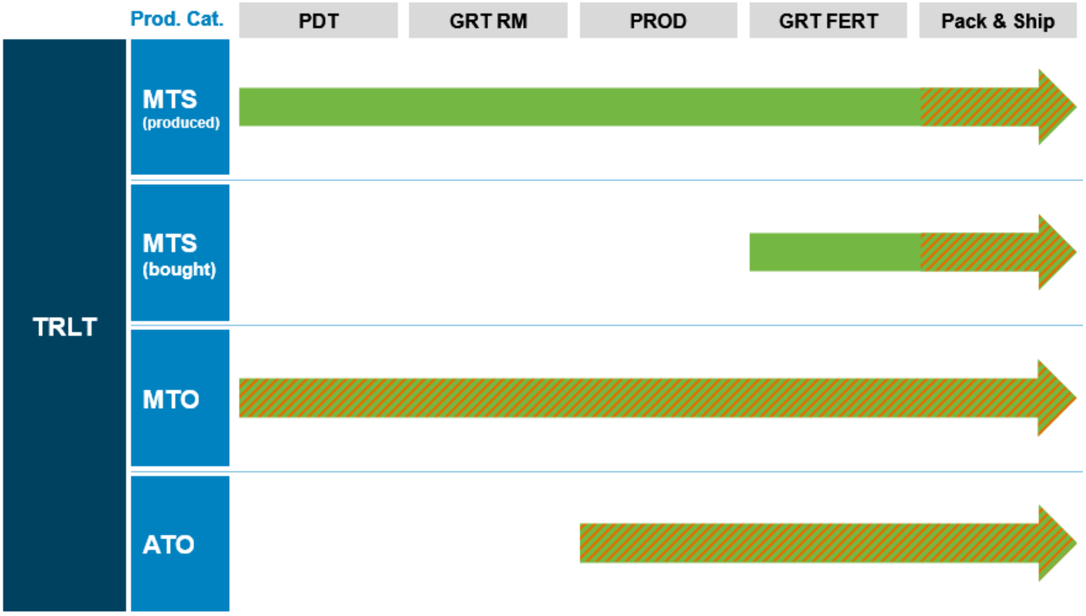


Figure 5.3.2: Lead-time components for the TRLT depends on the strategy group of a material: internal lead-times are shown in green, and external with a striped orange. Please note that for ATOs, components are produced before the finished good, and the TRLT for these are not illustrated.

MTS MTSs can either be bought from a supplier, or be produced. When bought, the good is quality controlled before sold. When produced, the entire process needs to be carried out, including purchasing, quality controls, production, and packing.

Please note that the external lead-time only includes the agreed-upon two days.

ATO For an ATO, the internal and external lead-times are identical. It includes the production time and the lead-time for quality control for the finished good.

MTO For an MTO, the internal and external lead-times are identical. It includes the entire process, including purchasing, all quality controls, production, and packing.

Lead-times for Salts

For the study, the lead-times of Salts were further analysed in great detail. The initial data collected from systems will be presented in this part.

Salts Lead-times Sample Previously, WC1 capacities was mentioned previously. To illustrate what lead-times could look like, a sample is given below for SKUs related to one particular type of *Material X*, which was included in the table mentioned. A full table of lead-times is not presented due to confidentiality reasons. Please see the sample below in Table 5.3.1.

SKU Name	Strategy Group	Original TRLT
Material X 0.5KG	MTS	100
Material X 2.5KG	MTS	100
Material X 50KG	MTO	100
Material X 100KG	ATO	100

Table 5.3.1: Lead-times for WC1 Material-Type X SKUs during the start of the thesis.

There are a few interesting things to note in the table. First of all, the only thing differing between these materials is the packaging size. However, the materials have different strategy groups, but the same lead-time. The process engineer verified that the two smaller sizes should be available on stock.

For WC1, all materials, with only few exceptions for the *Material X*, had 100 days as TRLT. The exceptions had 50, 10 and 0 days as TRLT: 0 illustrating that the materials were no longer used, leaving only two exceptions. In fact, for the Salts product category, 56% of SKUs had 100 days lead-time, and over 25% had 75 days. Meanwhile, ChemCo had an internal decision communicated to some customers that Salts should be delivered within 40 days.

Several Sources of Data The researchers found problems early on when getting introduced to the data, trying to analyse the lead-times provided. Often, there were several different sources for similar information. One such example was the GRPT, which required close collaboration and dialogue with the quality control division before the "best" source could be established, meaning the source which technically included the right data; in the mentioned example, this would be the start and finish times for the test. This discussion continued for all components of TRLT.

In addition to the ERP-system including several sources of similar data, some data was missing. Most notable was the example of purchased materials lead-times, where the ERP-system could not provide time stamps as for when material was ordered, and when it was received. Moreover, such history could be problematic, as ChemCo may have requested the material to be received earlier or later than agreed lead-times. In the case of procurement, one manager had himself kept several months history of exceptions-free orders with exactly that data.

Moreover, the researchers noticed over time that for procurement of raw materials, the times used by the systems were not identical to those used in the *Master Data*, which should describe material. Instead, certain *Info Records*, an additional information set, contained the updated times which had to be used for any analysis.

5.3.3 Execution of the Plan

Once the plan is frozen, it is up to production management to execute it. Production management use the schedule to make a detailed plan, assigning resources available to produce and deliver the goods. Operator assignment, equipment assignment and the mobilisation of raw material are prepared. Production managers and process engineers work together to solve problems occurring during production, such as a shortage of staff, or machine break-downs.

Normally, the *Frozen Schedule* is not changed unless there are critical problems, such as equipment failures or raw material problems.

As for the technical aspects for how orders are converted, and relating lead-times, please see Appendix A.1 on page 135.

5.4 Current Salts Performance as Measured by ChemCo

This section will illustrate the current supply chain performance as measured by the KPIs presented in Section 4.3.2 on page 68. These are important as they are the social construct which ChemCo uses to measure performance of projects.

5.4.1 Key Performance Indicators

Throughout this report, the colour blue will be used to illustrate OTIF, while green will be used for backlog, so that readers can easily interpret graphs presented.

OTIF Performance

OTIF for the first three weeks of the thesis project is presented in Figure 5.4.1. ChemCo has a long-term goal of reaching 95% OTIF, but communicated a first target to reach a somewhat lower level. This first target was set as ChemCo required a push in performance.

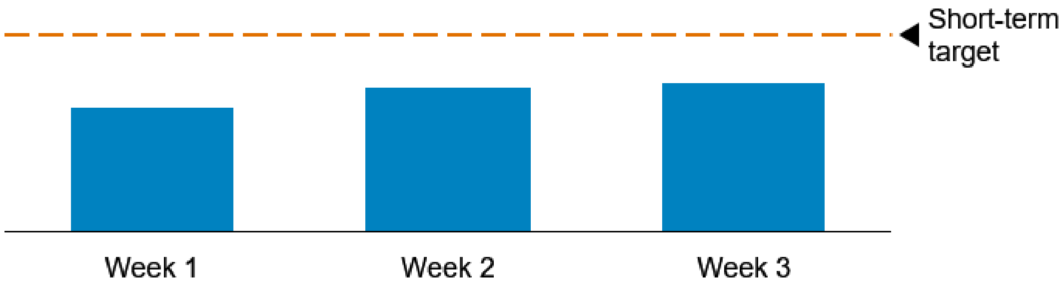


Figure 5.4.1: OTIF during the three weeks of the thesis. Actual weeks or numbers are not shown due to confidentiality reasons.

Backlog Performance

Backlog for the first three weeks of the thesis project is presented in Figure 5.4.2. ChemCo did not set up a specific backlog target for Salts, although the PO and PS explained that the levels at the beginning of the thesis were seen as ”very bad” and required instant action, illustrated by an expected level.

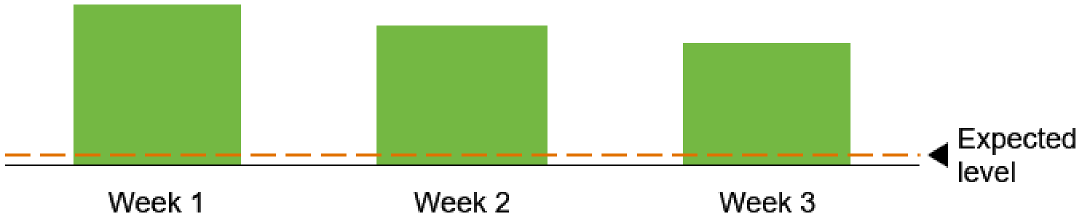


Figure 5.4.2: Backlog during the three weeks of the thesis. Actual weeks or numbers are not shown due to confidentiality reasons.

Comment on Performance

The Salts production had experienced experienced a large performance decrease after the holidays, implicating a substantial backlog and a low OTIF performance. Both KPIs present a substantial performance increase during the first weeks, resulting from a push to solve previous problems.

Inventory Health

Inventory health data was not obtainable on the level needed to conduct any analysis for the thesis. Problems with inventory health were seen as firm-wide, where supply chain managers manually approved all procurement orders in order to solve the most critical problems. As a result, measuring the inventory health would only measure the decisions of the managers *before production*, rather than actual production performance.

5.4.2 Planner Workload

The planners PL:P and PL:S explained through dialogue that the planning process caused frustration on a daily basis. Both planners agreed that their planning was largely unassisted by the system, where PL:S explained that the system did not add any efficiency or effectiveness to her work, as she had to create manual production schedules for Salts due to large backlog and changes from customers. As a result, the PL:P explained how he could not utilise the system for procurement, as packaging materials required for Salts often were specified much later than required according to lead-times. Consequently, he had to stock such materials based on experience and historical demand patterns.

Chapter 6

Analysis

6.1 A Discussion on the Problem at Hand

According to Coughlan and Coghlan (2002), the first step in all action research is to reach an understanding of the questions and the rationale. This section will discuss the rationale behind the research questions and what is driving the need for action. This discussion will be the groundwork upon which all subsequent analysis will rest.

Introducing this section are the research questions as presented on page 3:

RQ1: How should lead-times be calculated at ChemCo *Salts* production?

RQ2: What technique should ChemCo use to incorporate such calculations?

RQ3: What impact could ChemCo expect from the developed technique?

6.1.1 Current Situation in Relation to Research Questions

At ChemCo, there is currently a discrepancy between system lead-times and the time it takes for material to reach the customer - the actual lead-times. According to supply chain managers, this leads to dissatisfied customers and dissatisfying KPI performance, especially with regard to the OTIF- and backlog-measurements. Updating lead-times could alone improve OTIF and backlog-performance, as system generated delivery dates would better match actual material release days from production. Lead-times are important from a customer satisfaction perspective: having competitive, and realistic, lead-times enables timely deliver.

Management's goal reflects the overall industry struggle as suggested in literature. Gocke and Lang (2015) and Budde (2011) discuss the challenge of increasing performance in order to compete with emerging markets; two ways are considered: (1) increasing cost efficiency or (2) increasing quality and service level. ChemCo can already be described as a producer of complex and high grade products, thereby being a quality actor. Hence, the added value from quality as described by the PS is a way to compete that is reflected by academia. However, cost efficiency is also important, as emerging players are believed to move towards higher product complexity.

An initial literature review on lead-times demonstrated that researchers have discussed how the quality of lead-time data affects performance, and different methods of setting lead-times (Milne et al., 2015). Lead-times' importance on delivery performance is further discussed by Buzacott and Shanthikumar (1994), concluding that small discrepancies in lead-times can have detrimental effect on delivery reliability.

Using analytics is becoming increasingly important in order to perform. In fact, top-performing firms are prone to using analytics for decision-making (Chae et al., 2014; T. Davenport and Harris, 2013; Liberatore and Luo, 2010). As mentioned by Chae et al. (2014) and Dionne and Kempf (2011), data quality is key to perform; notably, input data has to be good for the output quality not to suffer.

With these points in mind, answering *RQ1* could hopefully help ChemCo improving its KPI performance. Answering *RQ3* would evaluate the impact a new lead-time process would have on ChemCo's performance. As literature on the process of updating lead-times within a company is quite limited, in particular with relation to empirical cases and in company contexts, the authors hope that answering *RQ2* could help provide a technique for determining lead-times in the process industry and in contexts similar to that of ChemCo. The research could provide academia with important contextual considerations, as well as provide companies with an idea for an easy, actionable, and yet efficient and effective technique.

To summarise, ChemCo experiences a discrepancy between system lead-times and actual lead-time performance. ChemCo's management believes this impacts performance negatively. Researchers have shown that this is not a unique problem. Consequently, the area of research is found interesting, and analysing lead-times seems like a feasible approach to the problem at hand.

6.1.2 Initial Lead-time Problems

Lead-times should describe the budgeted time it takes to produce a material. It is important to keep such times updated to achieve performance targets (Samaranayake, 2013). At ChemCo, the authors noticed initial problems with the lead-times available. For the sake of simplicity, the WC1 workcentre is discussed, as discussing all workcentres in-detail would be to comprehensive for this analysis, and arguments apply to several cross-workcentres.

For WC1, it has already been presented that most SKUs, two excluded, had 100 days internal total replenishment lead-time. Meanwhile, it was also presented that ChemCo wishes to deliver Salts within 40 days to customers. While this may be possible for MTSs, as the 100 days would technically illustrate the internal production time, it would be a technical impossibility for both MTOs and ATOs, as the TRLT for those items would denote production, and for MTOs also procurement. Thereby, it can be said that the lead-times are not reflecting the suggested strategy. This holds particularly true when considering slack: lead-times should be over-estimated to allow for feasible planning, as suggested by Milne et al. (2015). Knowing that ChemCo has a demand review walking through top deviators, it can be stated that forecasts are not always accurate, emphasising the need for certain safety buffers.

The noticed problem could implicate that the current segmentation of materials, based on their supply-chain attributes, were not conducted in agreement with customer expectations and communication. This argument is based on what segmentation should reflect according to Jin and Gilligan (2014). Thereby, the physical function and market mediation function of the supply chain would not be coordinated (Fisher, 1997; Christopher, Peck, et al., 2006).

6.1.3 Certain Care with Intervention

Bendul and Knollmann (2015) mention how careless updating of lead-times can cause a vicious cycle leading - the lead-time syndrome: frequent updates lead to short-term variability in lead-times, which planners then try to counteract with subsequent updates to lead-times. Ultimately, it is important not to update lead-times too frequently, in order to ensure that the adjustments or updates are not contra-productive.

In the case of ChemCo, this does not only mean that the researchers should not carry out direct interaction in the live system to test the feasibility of the solution, but also implicated that the steering group had to focus on thorough discussion and analysis of solutions offline before implementing theorised techniques.

6.1.4 The Structure of the Analysis

Following the method of action research, the work at ChemCo was cyclical and iterated. This is well aligned with the developed methodology framework illustrated by Figure 2.3.5 on page 26.

The research was conducted in three main cycles, where one cycle corresponded to one distinct approach at updating lead-times. Given the cyclical and iterative nature of the research, the chronology is of high importance to gain an understanding of the process of developing the technique. In order to provide such an understanding, in addition to actually illustrating the work carried out, the analysis is structured according to the three cycles. In addition, an initial discussion is conducted concerning applicability.

The research questions will be answered and analysed throughout the analysis-chapter. A summarised answer to each question will then be presented in the recommendations chapter starting on page 124.

6.2 Anchoring a New Process in the Organisation

One of the major problems with developing a new or improved process is the risk of the organisation reverting to "the old ways" (Laguna and Marklund, 2013; Ljungberg and Larsson, 2012). This section will briefly discuss suggestions made by academia on how to make sure new processes become stable and permanent in an organisation and how such theory can be applied in the case of ChemCo.

6.2.1 Cross-Functional Development

By approaching the creation of a new process with a cross-functional, business process perspective, the probability of the new process being implemented and accepted by all affected departments increase (Rummler and Brache, 1991). In agreement, the development of a new process at ChemCo involved people from the supply chain, planning, engineering and IT. Notably, the team ranged from management to people carrying out operational work. The goal was to assure that all involved functions was given opportunity to give input on the process, the desired improvement, and ongoing action - thereby anchoring the new process in the organisation.

Considering the three steps of developing a new process suggested by Rummler and Brache (1991), the first step, identifying the need for change, had already been taken by managers: lead-times needed be updated or adjusted. Such a requirement was agreed upon by remaining functions, further agreeing with Rummler and Brache (1991).

6.2.2 Project Ownership and Performance-Measurement

According to Laguna and Marklund (2013) and Ljungberg and Larsson (2012), finding clear responsibilities and a project owner is essential. In order to substitute the current lead-time setting with the usage of a new technique, clear responsibilities should be included. While this was clearly done for the development project, responsibility delegation going forward is presented in the end of the analysis. The PO recommended a supply chain manager, the PS, as the principal owner of the project.

The importance of measuring performance effectively and making sure the measuring is reflecting company goals is discussed by Bourne et al. (2003). The authors, in agreement with the PO, concluded that some already used KPIs, backlog and OTIF, would reflect the long term impact of lead-time adjustments, as proper lead-times would lead to fewer OTIF hits and hence smaller backlog over time. However, projects should also be analysed qualitatively, as the measurements are not optimal. First of all, both measurements are not directly measuring lead-times, but also reflect customer demand, capacity problems and strategy groups; correcting lead-times does not upgrade capacity or change strategy groups. In addition, the authors noticed what was described as poor KPI-performance upon the start of the project, meaning that a correction of lead-times would require a long period of time to pass to correctly illustrate resulting performance. In fact, an initial update could even decrease KPI-performance due to short-term variability, as described by Bendul and Knollmann (2015).

The authors reflected on tests with higher validity, and concluded that a better way to measure performance would be to directly measure lead-time for newly placed orders. While such a measurement has high validity, as the impact is directly measured, it is problematic in practice with large backlog, as months of backlog effectively postpones production outside of measurable scope. The authors do maintain, though, that it would accurately measure lead-time performance - why such a measurement is recommended for ChemCo going forward.

Concluding, the researchers believe that backlog and OTIF are secondary tests, which can be used to a certain degree to give an idea of impact. However, performance need to be analysed also qualitatively, and in regards to other production-factors.

6.2.3 The Ineptitude of Overly-Mathematical Approaches

Many techniques for setting lead-times suggested by academia are mathematical, either calculating an optimal solution or simulating a best possible solution given large tests. Although approaches can provide rich output, implementations are seen as time-consuming to develop and maintain (Hegedus and Hopp, 2001; Milne et al., 2015).

Most mathematical models require comprehensive assumptions, why they may be impractical, or even inappropriate, for practical use. Such models, in addition, may require being updated dynamically - sometimes as often as on a per-order basic (Hegedus and Hopp, 2001; Milne et al., 2015). Such models at ChemCo would be more complex than in cases suggested by academia, namely due to a large number of SKUs, shared resources, several ingoing components and a multi-stage production. In addition, the supply chain team is under high workload, and has experienced high turnover over recent years. Resulting, the efficiency of a developed solution is of importance for the technique to be feasibly implemented and used.

These thoughts were echoed by ChemCo's management during early research; the PO and PS expressed concerns regarding complexity. They wished for an actionable tool that was understandable, easy to update, and that didn't require substantial mathematical knowledge; they preferred a clear input-output relational methodology over a "black box", as suggested by Milne et al. (2015). Moreover, they emphasised how the model should be understandable for the entire team, where the planners who would see the tool regularly had no background in mathematics.

With this discussion in mind, the authors realised that a solution could not be of advanced mathematical character in order to work in the given context, as explained not only by action research, but also by the view chosen: the future had to be constructed from within, as suggested by Gammelgaard (2004).

6.3 The Determination Approach

This section will presented the first cycle of the project and its related analysis. The first cycle focused on getting an overall understanding of lead-times agreed upon by the entire steering group. Doing so, the group tried to determine lead-times analytically based on their production characteristics.

The components presented in this chapter were analysed by the steering group during the workshop. The workshop included in-detail discussions on both technical aspects, and how each component is, and could, be estimated or decided.

6.3.1 Determining Lead-times

After having realised initial problems with lead-times, the steering group agreed that a technique was needed for updating lead-times. Milne et al. (2015) suggest three ways to updating lead-times, where his first analytical approach was seen as a good start to the project. Ultimately, to analytically determine lead-times, one needed to understand the production and processes, why it would contribute to the groups knowledge development. Moreover, it seemed like the easiest and most actionable approach, should it work. Ultimately, if a model could be found that would analytically determine lead-times, the times could actually be *determined rather than estimated*, eliminating the need for complex mathematics, vague assumptions or time-consuming calculations; such a solution was believed to be easy to implement in the organisation.

Keeping the goal in mind, it was key that a developed solution should be both understandable and efficient according to the steering group. As a result, the analytical approach could not be allowed to develop into something highly complex, as the benefits with using the approach would then be lost - the method would thereby be inefficient.

The Starting Point

Previously in this report, there has been a clear distinction between internal and external lead-times. Ultimately, the external lead-times would be easy to estimate if internal ones could be determined, as they would only include packing, handling and freight. Thereby, the problem would be to determine internal lead-times, why also MTOs becomes problematic. Orderpoints are presented again in Figure 6.3.1.

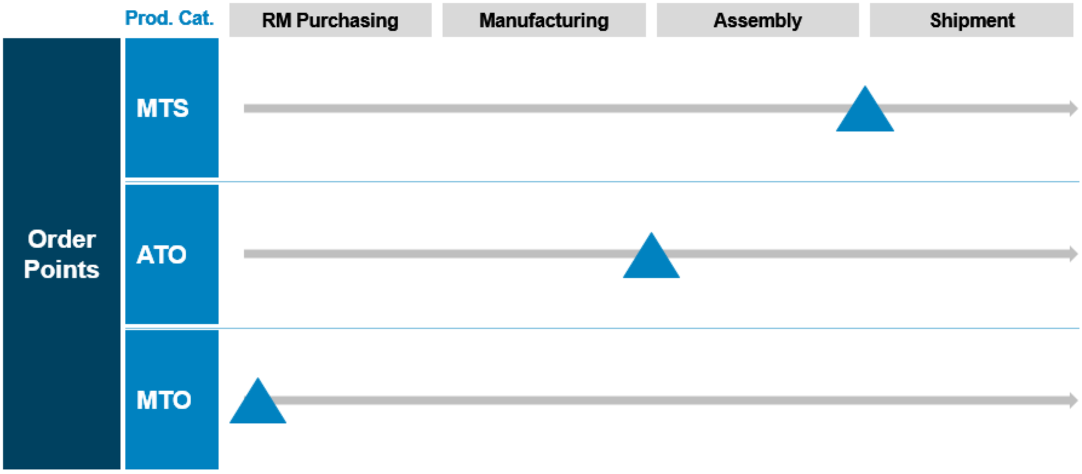


Figure 6.3.1: Revisited: the strategies explain where the order point is current: meaning which sub-processes comprise the total process.

At this stage, it is clear that four parts need to be considered in order to be able to analytically determine lead-times: the PDT, the GRT of the purchased material, the production time, an the GRT of the finished goods. The reader is reminded that production includes manufacturing and packaging. Ultimately, in order to determine the TRLT for a material, each of the four components should first be determined.

PDT

Purchasers have been described to not trust system PDTs, why buffers are frequently added to orders. This is not done in actual lead-time as slack, but rather on a per-order basis. The group thereby concluded that there are problems with current PDTs.

Purchasers described how PDT times are determined based on supplier communication to ChemCo. Unluckily, ChemCo has limited insight into the suppliers' value chain, why such times have to be requested. In addition, the PL:P described how PDTs often were dynamic, depending on purchased volume and supplier priorities.

Having deep-dived in PDTs with planners, the researchers concluded that PDTs were characterised by general unreliability and a "black box"-nature. Consequently, PDTs are unsuited for analytical modelling as they cannot be determined. The PL:P suggested that individual planners should be requested on bi-annual basis by planners, a project that was launched outside of the thesis.

GRT of Purchased Material

Current GRTs for purchased material is set to a fixed amount of days. In practice, different types of material require different time to analyse. Lab analysts may be working on several samples, as there is both *Active-* and *Passive Lab Time*. Consequently, waiting time can appear. In fact, a lab analyst at Plant A confirmed that materials rarely go through the lab without waiting time. Times also are dependent on current lab utilisation and priorities changing daily. It can therefore be concluded that lab times are actually stochastic, and cannot be directly determined.

A production manager at the plant explained that GRT times are often highly unreliable, and that materials infrequently are delivered at expected time. This has its foundation in how priorities are changed based on inter alia backlog priorities.

Ultimately, the stochastic nature of the GRT with several layers of complexity, inter alia from waiting- and passive time, make GRTs unsuitable to determine analytically.

Production Time

Manufacturing at ChemCo usually follows a linear formula base on quantity to be manufactured. However, production includes also break-downs, additional time due to failed tests, time needed to set up equipment and waiting time. It has been mentioned several times that changeover times are material dependent, and that waiting time depends on the production schedule. Such a schedule was not set, why campaign planning was not used to reduce changeover times, explained by Grunow et al. (2002) and Susarla and Karimi (2011). Additional unexpected downtime may appear.

Ultimately, production time has a stochastic nature. The PEN explained how complex the production time was, advising against spending time modelling it. Instead he and colleagues had calculated that 14 days should be used as a rule of thumb for production.

GRT of Finished Goods

The GRT of the finished goods is currently calculated in the same way as GRT of purchased material, id est a static number of days that should include testing time as well as downtime. The group concluded that also the GRT of Finished Goods was unsuitable to model analytically.

Role-specific Comments

Project Owner The PO, leading the workshop with he researchers, early on suggested that lead-times could not be determined analytically. However, he believed that a common understanding of the complexity and reasoning behind his argument would be a good basis for further action. In addition, he himself wished to gain further understanding as for the technical aspects of the system, which he and the researchers had not managed to gain through technical documentation.

Master Data Owner In evaluative discussion on lead-times, the MDO and ITE explained that the system has little support for directly calculating lead-times. Although SAP includes an offline-option to do such calculations, this module was not implemented or maintained, which would require far more resources that what was available at ChemCo at the time being. Thereby, calculations of lead-times would have to be carried out outside of the system in spreadsheet software such as Excel.

The MDO suggested that updated of lead-times should be calculated outside of the ERP-system, and then be manually entered in the system, something only two persons at the company could due to transparency and robustness reasons. Such an update would take a few hours of active operator time.

The researchers reasoned, together with the group, that using offline software to calculate software would be most suitable for ChemCo. Ultimately, people such as planners and engineers could review lead-times before they were updated in the system, which would thereby not fortify wrongdoings already in the system. Moreover, it would not require a sizeable investment in upgrading the ERP-system, which the PO believed was not a feasible solution, and definitely was seen as out of the scope for this project.

Packaging Planner The PL:P believed that an update to lead-times was needed. He himself tried to update PDTs as part of his work, and suggested that the same routine should be implemented not only for packaging, but for all raw materials. Moreover, he wished to formalise such a process on a regular basis.

Production Planner The PL:S appreciated the efforts taken to start updating system lead-times. According to the production planner, GRT times would be particularly hard to model due to material priorities. The commercial team sends a daily priority list to the lab, which he believed was impossible to predict or ”forecast”. This can be seen as an inefficiency in the supply chain, in relation to arguments by Samaranayake (2013), as the lab will lose valuable time with constant updated to testing orders.

According to the production planner, updating lead-times is a good start in the efforts to increase delivery accuracy. However, the planner calls attention to large backlog not only being a result of inaccurate lead-times, but also due to insufficient capacity.

Engineer The PEN was positive to the project, but was at the start of the project hesitant to determining exact lead-times, as he had experienced several sources of stochasticity in production from inter alia resource priorities, equipment utilisation, and equipment breakdowns. He further emphasised how changeover times can be reduced significantly by planning production differently, why he would prefer a final solution which did not only update lead-times, but also established a production routine.

6.3.2 Evaluation

Having looked at the partial lead-times, the group realised that the TRLT and its components unlikely could be modelled analytically. If possible at all, a solution would be both highly complex and of stochastic nature, not suiting the needs of ChemCo and the goals set up; the model would be far to complex to be efficiently implemented in the organisation’s operations. Ultimately, the warnings of Milne et al. (2015), stating that systems are usually far to complex to model analytically, proved to hold true in the case of ChemCo.

The group found that the production time showcased common problems described by Grunow et al. (2002) and Susarla and Karimi (2011), where the problems often lead to campaign planning to reduce changeover complexity. Although certain thought was spent on reducing changeover, no campaign planning was current at ChemCo.

Problems were well aligned with the speciality chemical industry, explained by Grunow et al. (2002) and Susarla and Karimi (2011) - many sources of complexity derived from a multi-product, multi-stage production with high variability.

Although campaign planning had appeared as a possible suggestion for adjusting lead-times, the group agreed that another approach to correcting lead-times should first be attempted before any actual production changes were carried out.

6.3.3 Summary

It is not feasible to determine lead-times at ChemCo analytically due to high complexity and stochasticity derived from complex processes. This complexity makes a possible solution both unpractical and inefficient.

6.3.4 Comments on Action Research

The researchers in the initial cycle further realised the importance of the context of ChemCo, why the view chosen made sense, see Arbnor and Bjerke (2009). Indeed, the problem required an understanding of the corporate dynamics and environment (Coughlan and Coghlan, 2002). Notably, the nature of the business created many requirements, and so did the skills of available personnel.

Establishing a group was important to build knowledge and to gather functions (Coughlan and Coghlan, 2002). Actually, the researchers found a main advantage with the first cycle to be a common understanding of the problem, where functions previously had very different views. Also, collaborative problem-solving worked well for the researchers to be included in the organisation, where they felt truly welcome (Ibidem). In addition, establishing a group within the organisation, including top-management, proved to help making sure that adequate resources were allocated (Ibidem).

The researchers noted that the problem indeed was of high importance for the organisation (Eden and Huxham, 1996; Westbrook, 1995), and needed the participation of the organisation (Coughlan and Coghlan, 2002; Reason, 1999). The researchers further noted how the problem developed over time, where evaluation happened concurrent with approaches (Eden and Huxham, 1996; Coughlan and Coghlan, 2002).

6.4 The Estimation Approach

This section will present analysis for the second cycle of the project. Having created a common understanding of lead-times and their technical aspects, the group had decided that lead-times could not be determined analytically. Instead, the group agreed that estimation could solve certain problems related to complexity of the previous approach.

Analysis in this section is based mainly on dialogue on role-specific meetings, but also on a workshop to evaluate a first attempt at the approach.

6.4.1 Evolving the Previous Approach

The group agreed that the first approach had its main problems in feasibility and efficiency, where stochasticity was a major problem. With this in mind, the authors decided to revisit the three approaches to setting lead-times suggested by Milne et al. (2015). Having excluded purely analytical approaches, two options remained: simulation based approaches and mathematical approaches.

Revisiting Mathematical Approaches

It has earlier been concluded that complex mathematical approaches in general are unsuitable for ChemCo. Using total processing time as basis for lead-times, suggested by Milne et al. (2015), was not an option either. First of all, it is seldom the main bottleneck of the process, and moreover, requires long time to validate, which would put the project outside of the scope of the thesis. In addition, for Salts, the TRLT can often be less than waiting time. Moreover, the approach would not be able to handle the complex nature of lab-times.

Simulation-based Approaches

A simulation-based approach would be one where the TRLT is simulated based on different parameters as input. The model could then, after being developed, be run as frequently as wished. Although such an approach would allow for dynamic updating with different supply chain conditions, such software is not available at the case of ChemCo. Furthermore, it was not seen feasible to invest in such software.

A Modified Simulation Approach

As discussed previously, in the case of ChemCo, spreadsheet software would have to be utilised for calculating lead-times. However, it has been concluded that workcentres are quite complex and have certain complex elements, why in-depth simulation would not be easily developed or maintained. Thereby, a solution would instead have to focus on an aggregated take of lead-times using historical values as the variables. The PO and PS bought into a suggestion to try an estimation-based approach where the TRLT would be simulated based on historical performance. The steering group thought that such an approach could prove feasible, although the PEN mentioned that extremes would have to excluded. In agreement with Buzacott and Shanthikumar (1994), quantiles were to be used to decide on safety buffers, which would help with his concerns. There was one underlying assumption behind the approach: history reflecting the supply chain conditions and performance. Thereby, the approach can be seen as a simulation with the actual supply chain, rather than a purely computational model.

6.4.2 Developing the New Model

The new model was to be developed in spreadsheet software as suggested by the MDO. The model included two levels of lead-times: (1) the TRLT, and (2) PDT, GRT and production. The conceptual model for an easy material is illustrated in Figure 6.4.1.

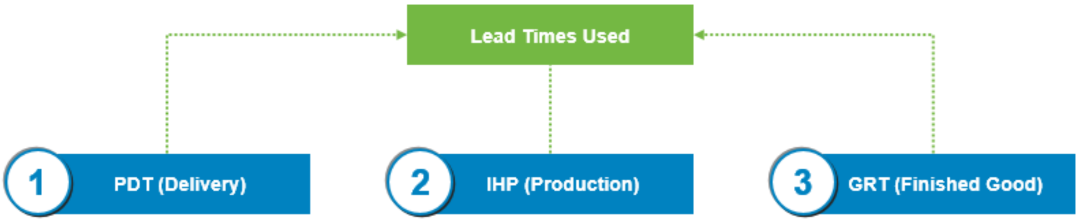


Figure 6.4.1: An illustration of the components that could be estimated with the modified simulation approach.

While the first conceptual model might seem easy to implement, several problems appear. First of all, data sets from the ERP-system were not directly linked, meaning that additional data had to be used to link the data sets uniquely. Secondly, for each of the three components, historical ERP-data would have to be used, and doing so, the 90-percentile values should be used according to a management decision by the COO, communicated by the PO and PS. Thirdly, the truly complex step, is realising that the PDT might not actually illustrate the time required to get the raw materials into the final good's production. Rather, the ingoing material may be a component, in which case the component needs to be fully modelled with its ingoing time, IHP and GRT - this is one of the problems with calculating lead-times, as suggested by Milne et al. (2015), Samaranayake (2013), and SAP AG (2001). In turn, the ingoing component may have ingoing components. A more correct illustration would look something like the one presented in Figure 6.4.2.

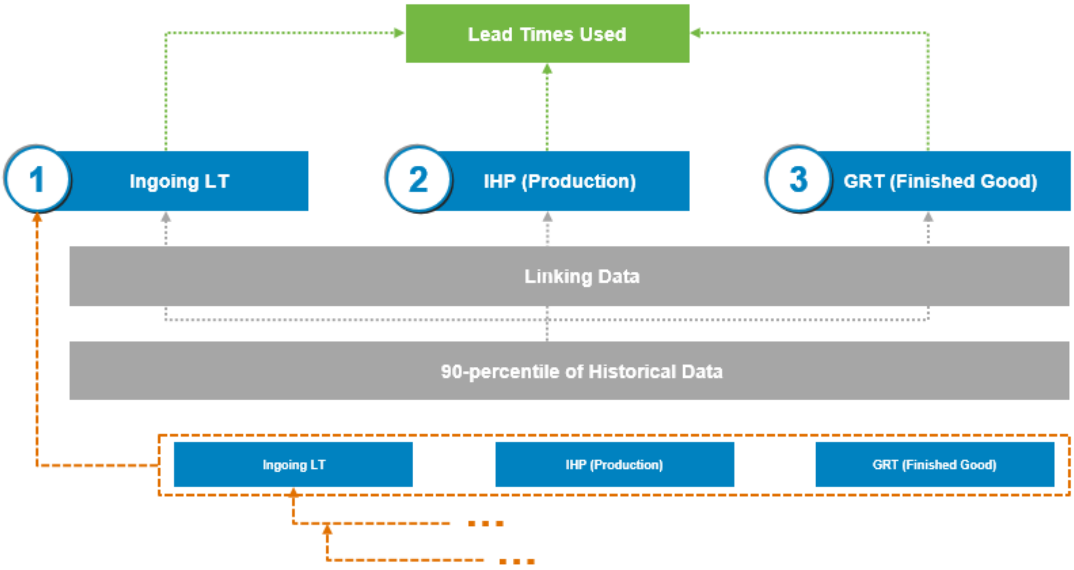


Figure 6.4.2: An extended illustration of the components that could be estimated with the modified simulation approach. Please note that each of the orange boxes naturally needs both linking data and historical ERP-data.

Available Data

The authors had thurough discussions with the MDO concerning available data in the ERP-system. In addition, follow-up discussions were needed with procurement, lab personnel, the PEN, and both the PL:S and PL:P.

All historical data was gathered from the start of 2015, as no major reconfigurations have happened with the Salts production since that point of time. The steering group agreed that data older than that might not be relevant for the current demand structure.

Material Master ChemCo has a material master which gives basic information about a material, including the current TRLT, PDT and GRT in the system. This data can be extracted directly from the ERP-system.

Info Records As for the actual and updated PDT in the system, the MDO believed that the material master was used; later discussions with planners proved that instead, info records were where updated PDTs could be found.

Historical Deliveries Historical deliveries cannot be extracted directly from the ERP-system with the needed data to carry out historical calculations. Instead, the data required joins several tables in the ERP-database. As mentioned in the empirical data, one procurement manager had himself kept track of such data, also adding additional fields and excluding orders which were extraordinary. The data included when deliveries were put in, when they were scheduled to arrive, and when they arrived.

Production Time Production data was available, but not in any granularity. Instead, the PEN kept track of detailed steps in the production, where he calculated 14 days to be sufficient for the production for Salts, including manufacturing, changeovers and in-production tests. The number allowed for a small buffer, dependent on material.

Historical Quality Control As for historical quality control time, the ERP-system included several tables with the needed data. The problem was that the different tables included different fields for times, why consultation was required with lab personnel before the correct data was identified. The data showed when a lab sample started, was targeted to finish, and when it finished.

Bill of Materials The system included one large table showing which outgoing materials existed for every ingoing material. By using an advanced database-tool offline, the authors managed to expand the table to show each level of ingoing materials.

Linking Data Several sources of data used for mapping was used. Mapping was done to planners, workcentres and production areas.

Literature Input on Creating a Statistical Model

Several authors describe the need of simplifying mathematical models with simplifying assumptions. Common assumptions are to ignore backlog or replacing the modelling of some lead-times with standardised times (Milne et al., 2015; Samaranayake, 2013). Consequently, the authors found the group's decided action on production times to be acknowledged by theory, in addition to making sense in the context. Further simplifying assumptions were required for the model to be easier to understand, take action on, and maintain. Focus should be directed towards modelling the sources of lead-times that are easy to model and that contribute to output. For this model, it meant that waiting time, changeover times and the complexity of production scheduling were simplified, instead relying on the PEN's experience.

The conceptual model explained is part of supply chain analytics, and moreover data management resources. Resultingly, for the model to increase operational performance, the model would require maintenance and data integrity, as output is highly dependent on the quality of the input (Chae et al., 2014). Consequently, the input integrity needs to be reviewed before potential implementation.

Model Logic

The model was created in an offline spreadsheet software, where data was loaded from the ERP-system and the procurement manager's separate data. Instructions were written on each separate sheet to allow for easier updates by ANA1 and ANA2, who took part in design decisions and the conceptual model development. Below, the logic used for each component is presented below.

Ingoing Lead-time To calculate ingoing lead-time, the model would check for ingoing components, as explained by the logic below in Listing 6.1:

Listing 6.1: Logic for PDT calculation

```
IF BOM exists for SKU
    THEN Find longest ingoing TRLT
    ELSE Suggest a new PDT
END IF
```

The new PDT suggested was calculated according to Equation 6.4.1.

$$PDT_S = PDT_O + (\Delta PDT)_C \tag{6.4.1}$$

Where PDT_S denote the suggested PDT, PDT_O is the original PDT used by the system, and $(\Delta PDT)_C$ is the calculated suggested difference in PDT for 90% of material to arrive on time. The suggested difference was calculated using advanced Excel-logic based around the function $PERCENTILE.INC$. The desired percentile was incorporated in the model so that it could easily be updated through a dropdown list. The incorporated percentile acted as a safety measure for lead-time, as suggested by Milne et al. (2015), T. v. Kampen et al. (2012), and Buzacott and Shanthikumar (1994). As uncertainty existed in timing (Ibidem), it was seen appropriate.

Production Lead-time The production lead-time for all Salts was set to 14 days; the option was incorporated in the model so that it could easily be updated through changing a cell on a special input-sheet.

Quality Control Lead-time The GRT should only include the final GRT, as ingoing materials have already been included, should a BOM exist. Thereby, the logic could mirror the one for PDT_S, and is shown in Equation 6.4.2.

$$GRT_S = GRT_O + (\Delta GRT)_C \tag{6.4.2}$$

Denotions are analogous do those used by equation 6.4.1.

Total Replenishment Lead-time Finally the system TRLT was compared to the sum of the ingoing components, as suggested by Equation 6.4.3.

$$TRLT_S = GRT_S + IHP + PDT_S \tag{6.4.3}$$

Where $TRLT_S$ denote the suggested TRLT, GRT_S and PDT_S have been presented above, and IHP the in-house production time.

Comments on Model Structure

The finished model includes over 35 separate sheets in order to allow for dynamic updating, transparency, and a clear structure. Notably, substantial energy was spent to assure that the model would only require updates in a few clearly marked sheets, meaning that everything had to be based on those few sheets.

6.4.3 Results

105 active materials were found to be mapped to Salts production at Plant A. Out of these, 84% were produced internally according to the ERP-system, 14% were not final goods or incorrectly inactivated in the system, and 2% were procured externally. Please see the division presented in Figure 6.4.3.

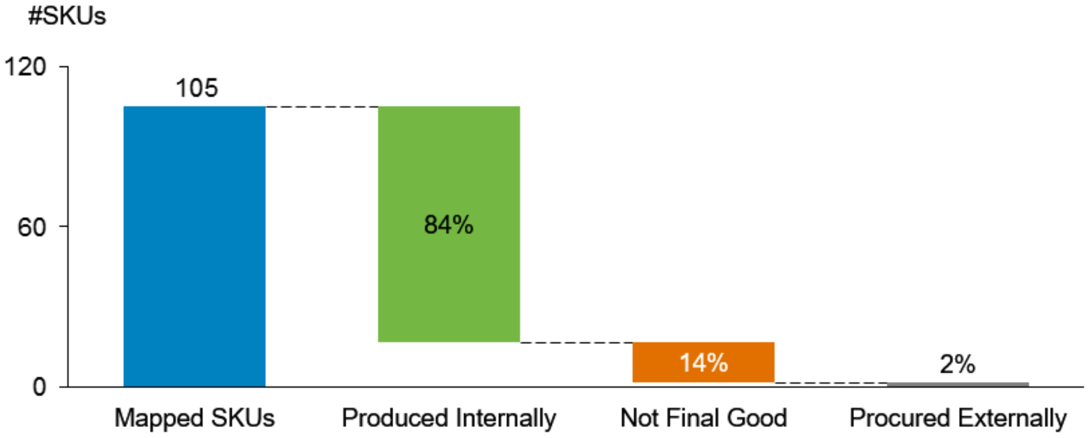


Figure 6.4.3: A break-down of materials analysed in the lead-time model created.

Non-final goods were not analysed with regards to final lead-time. As for the two materials marked as procured externally, both materials lacked procurement data.

Available Data-points

Out of the remaining 88 materials, the number of historical data-points used is illustrated in an histogram, see Figure 6.4.4.

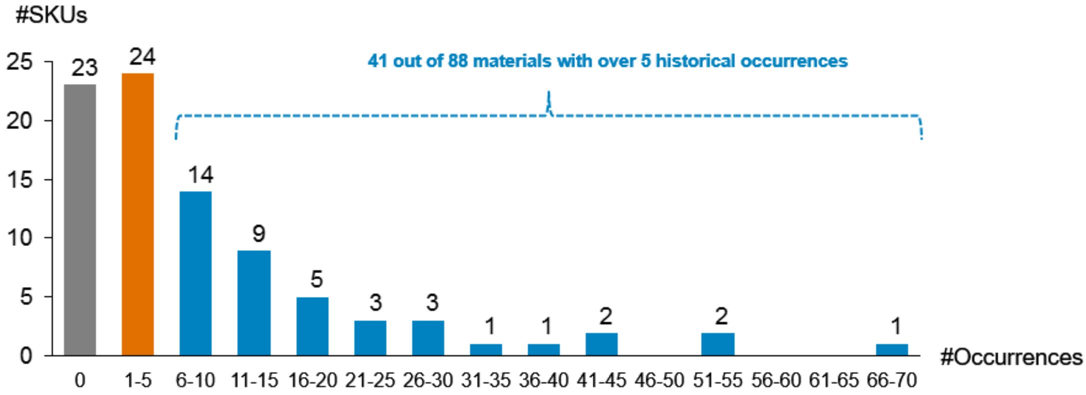


Figure 6.4.4: The number of SKUs per frequency of historical data-points among the 88 materials produced internally.

From the data, the reader should note that 23 SKUs (26%) had no historical data-points, why they could not be simulated in the model. In addition, 24 SKUs (27%) had five or less historical occurrences. In model development, the planner and production engineer clearly said that they did not feel comfortable implementing lead-times with so few data-points; the remaining steering group from the company's side bought into their arguments. The model was adjusted accordingly, as it had to fit the requirements of the organisation. Ultimately, 41 SKUs (47%) remained for further analysis.

Final Sample

Among the remaining SKUs, analysis was made in regards to the change suggested by the model. This is shown in a histogram, see Figure 6.4.5.

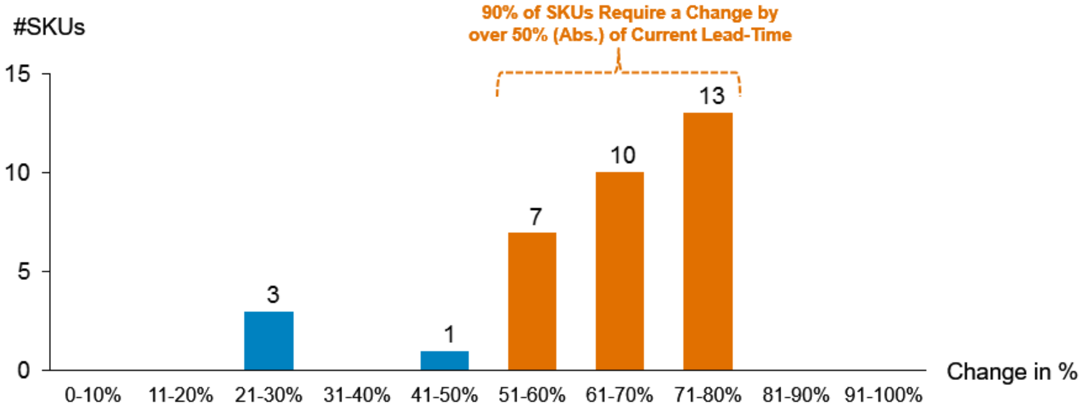


Figure 6.4.5: The number of SKUs per suggested change group among the 41 materials with over five historical data-points.

Strategy Groups

In addition to results above, the total sample was analysed with regards to strategy group, illustrated in Figure 6.4.6.

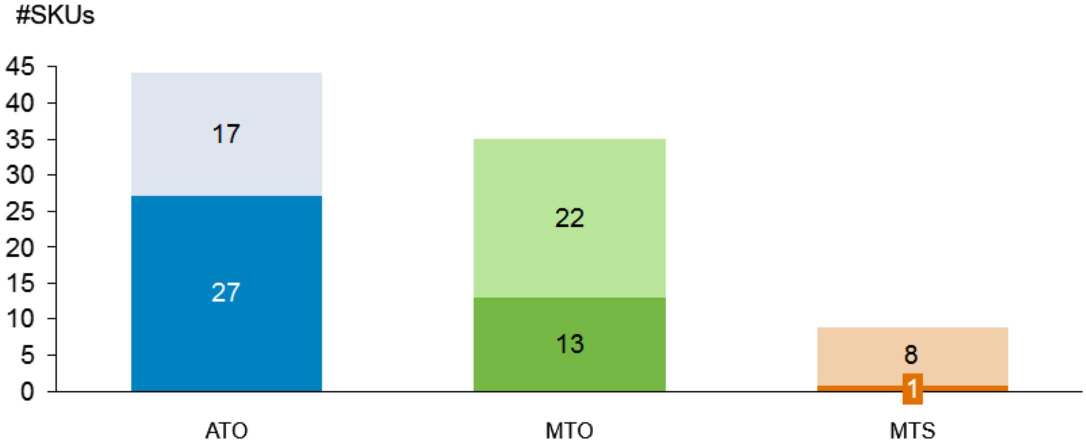


Figure 6.4.6: Strategy group used by SKUs in the Salts production category, the final sample is coloured solid, where excluded materials are lighter/transparent.

6.4.4 Evaluation

Having run the model and adapted to a sub-set of the materials as defined by the company, the steering group met in order to discuss the results.

Inactive- and Procurement Materials

Initially, upon studying the results, the group concluded that it was surprising that there were 8 materials among the 15 non-final goods that were not active at the plant, although not having been fully marked as inactive in the system - a rule that was discovered by the authors late in the simulation-building. The team discussed why such a situation could appear, and concluded that temporarily disabled items may have been forgotten, and are thereby left as inactive, but not disabled.

The authors presented the two items that were final, but set to procurement type external. Upon reviewing both items in detail, it was concluded that both materials should be produced internally, explaining why no procurement data was available.

Data-Points

What really surprised the group was how few data points existed for several materials, where it was clear that a few materials constituted a majority of production, tests and purchasing. In fact, the researchers noted that 20% of materials had over 70% of data-points - close to the Pareto assumption; 30% of materials contributed to less than seven percent of historical data-points.

As mentioned already, the group decided not to simulate lead-times for materials with less than five data-points, as they believed it to be too few samples to give an accurate simulation. Although mathematically and academically a volatility analysis could be conducted to further examine such samples, the group decided not to pursue that option with regards to time available. Moreover, the group wished not to update lead-times if not needed, in order to avoid the lead-time syndrome (Bendul and Knollmann, 2015).

Suggested Change

The group agreed that the suggested change to lead-times was much higher than what was expected; indeed, 90% of SKUs required a change of 50% or more of the current TRLT, which was seen high. The researchers argued that such a change could be logical, due to the very high lead-times current, see examplia gratia WC1 materials. The group agreed, although not wishing for too radical updates to materials.

Strategy Groups

The group spent a majority of the workshop discussing the segmentation of materials, and in particular in the sample which could be corrected. Overall, the group was highly surprised that there were so few MTS-items, which should be constituted of key materials purchased often. While the ATO-group made sense, as many Salts could be produced, and be packaged later, the MTO surprised. The group deep-dived and noticed several container-sizes being MTOs, although other sizes of the same materials were ATOs, suggesting that errors existed. The main problem found by the group was that the existing segmentation did not feed into production priorities, causing inefficiencies in planning, and not guiding actual production carried out.

Model Feasibility

Overall, the group agreed that the model had certain applicability. Problems existed in feasibility, as the model ultimately became what one member described as an ”offline ERP-system”, due to its complexity and size. The model took a workday to prepare and run, and only a few computers available at ChemCo could run the model due to complex logic and links. While the time required was not seen problematic, the PD:P and PD:S looked through several materials in great detail, and explained that there were too many irregularities for materials to purely rely on the model. Together with the PEN, they agreed that materials would have to be manually checked one by one before any change. Thereby, feasibility was problematic mainly in the amount of work required *after* the simulation, where the PL:S mentioned that such a solution would not be much better than manually updating materials.

In addition, the main problem found by the group, as first expressed by the PO, was that this solution would treat a problem regarding production efficiency, rather than solving it. The group agreed that segmentation was a major problem, and that certain directly faults existed in the data.

The PL:P wanted to use the model for packaging material, to see historical performance and suggested safety buffers. He piloted such a project, and realised that GRT-times set in the system for packaging materials should be revised. As for PDTs, he and the researchers noticed that several times in the system were incorrect, and moreover that history could not always guide updates, as several large providers had either had notable backlog or pushed materials for ChemCo. Thereby, history would show extremes rather than a normal case, even when adjusting for percentiles.

Ultimately, the team decided that a solution was needed to solve both the prioritisation in the production, and the related lead-time accuracy. However, the developed model could be used to improve data integrity and maintain components of lead-times.

6.4.5 Summary

While the model showed promise with regards to certain materials, the group decided, after an actioned pilot, to solve production-related problems, and their implicated lead-times - *the problem should be solved, not hotfixed.*

6.4.6 Comments on Action Research

The researchers noted how the second cycle focused more on action; theory developed over time, and several adjustments were needed, such as where to get data - neither would be possible in traditional research (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Reason, 1999; Westbrook, 1995).

As for the problem, it was clear that the root-cause of the problem at hand was not fully understood before the cycle, but required action and common collaboration to be identified. Production problems were caused by lead-times, but lacking prioritisation proved to play a larger part than first identified, in turn impacting lead-times. Without the cyclical nature of AR, such a conclusion would never be found. AR in this case developed knowledge and understanding, and thereby moved the project closer to the real organisation problem with genuine practical value (Eden and Huxham, 1996; Dubois and Gadde, 2002; Reason, 1999; Voss et al., 2002; Westbrook, 1995).

After the second cycle, the researchers experienced advantages of AR: the learning they had gaines through collaborative problem-solving could not have been gained otherwise. Moreover, a momentum was created within the organisation due to the project's importance (Eden and Huxham, 1996; Coughlan and Coghlan, 2002; Reason, 1999; Westbrook, 1995). Interestingly, the researchers noted how several persons became interested in the academia for the approach - the lead-time syndrome was used by three persons arguing against action in live systems.

It should be noted that the researchers experienced problems in keeping themselves distanced from the organisation when working so closely with solving a problem. It was not always clear if a situation constituted a social construct, or a bias. Consequently, the researchers carefully observed and reviewed field notes on a daily basis with their methodology in mind, making sure that the framework acted as a base for the research.

6.5 The Adjusting Approach

This section will explain the third cycle of research. After having evaluated the second approach, the group acknowledged that adjusting lead-times would only solve a partial problem, and that statistics could not be used as the sole mean for updating lead-time. The researchers thereby investigated further options, examining the option to adjust production rather than just trying to correct it.

6.5.1 Evolving From the Second Cycle

It was since long concluded that changeover times and waiting times cause complexity both in ChemCo's industry and at ChemCo. With this in mind, literature was reviewed, searching for a focus on changeover times in the chemical industry. The concept of campaign planning became a focus of interest, further introducing the concept of cyclical production scheduling.

Finding a Different Approach

In discussions on the problematic modelling of lead-times, the PO first introduced a new way of looking at the problem: if lead-times cannot be modelled given the current production situation, perhaps they should be the result of remodelling the production planning? Such a solution could also prove to increase production efficiency, helping with backlog. Academia's suggestion to such an approach was campaign planning, commonly used in the chemical industry to minimise changeover time and increase production capacity (Grunow et al., 2002; Susarla and Karimi, 2011).

Campaign planning was not implemented at the production for Salts. The current backlog for several SKUs lead to a shortsighted planning, where too many materials were produced, hampering efficiency. The researchers recognised the phenomena as the "vicious cycle of poor production planning" Dionne and Kempf (2011), see Figure 6.5.1.

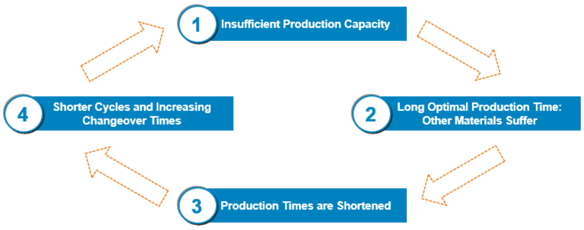


Figure 6.5.1: Revisited: the vicious cycle of poor production planning as described by Dionne and Kempf (2011), illustrating how insufficient production capacity can lead to a decrease in production capacity

The authors realised that substantial backlog could be a result of insufficient capacity during available time. As the production time for one material may hamper or neglect others, shorter cycles are planned to produce different materials in lesser amounts, leading to overall lower production. To summarise the cycle, in fear of neglecting some salts, several salts were produced when optimally only one should be produced, decreasing capacity and increasing backlog.

The authors, PO and PS hypothesised that implementing campaign planning at ChemCo would allow for delivery accuracy, as the production would be standardised. In addition, it could potentially increase output, as the vicious cycle described by Dionne and Kempf (2011) could be avoided. With campaign planning, target lead-times would work as the foundation of a structured process, rather than an unstructured process being the result of inadequate lead-times - *instead of letting the lead-times fit the process, the process would fit the lead-times.*

6.5.2 How to Design a Campaign Planning Model

The process of developing a campaign planning tool was split in three questions.

First of all, one must answer one key question: *What materials should be produced?*. While this is done in all types of planning, a set campaign in terms of timing requires decisions and prioritisation given the current demand situation and available capacity.

The main idea of campaign planning is to plan several batches of the same material consecutively in order to decrease changeover times. However, a trade-off is involved as producing too much of a material increases working capital and inventory (Grunow et al., 2002; Susarla and Karimi, 2011). A key question remains: *How much should be produced of a material in a given time frame?*

A problem resulting from the question of which materials to produce is *In what order should the materials be produced?* Generally, there are benefits to producing certain materials in sequence, as it could reduce changeovers further.

With the commercial target of delivering salts within 40 days to customers, not reflected by current lead-times as seen for exampli gratia WC1, the PO decided that an approach should be developed around a 30 day campaign period. That way, materials with enough demand would be produced regularly with 10 days left for GRT, which should never take more than three days, and packing. Such a safety buffer would further allow for storage, unwanted downtime and holidays etcetera.

What Materials Should Be Produced?

Cyclic design was acknowledged in theory as a suitable approach due to high changeovers, where research has shown that cyclic planning can increase output significantly (Schmidt et al., 2001; Ashayeri et al., 2006; Olhager, 2016b).

Ashayeri et al. (2006) suggests that all materials of a workcenter should be produced each cycle. In the case of ChemCo, several materials have minute demand, why such a solution would reduce campaign lengths significantly, leading to an overall decrease in output, rather than increase. Thereby, his suggested solution was not found feasible. Instead, the researchers looked into the suggestion by Olhager (2016b): to use segmentation to decide which material to produce. To create such a segmentation, decisions are needed as for how many classes are needed and how the borders between classes should be determined (T. v. Kampen et al., 2012).

Literature suggests several bases for segmentation, such as ”Innovative/functional products”, ”The three dimensional model”, ”Customer segmentation”, and ”ABC-analysis” (Flores and Whybark, 1986; Fisher, 1997; Christopher, Peck, et al., 2006; D'Alessandro and Baveja, 2000). The group deemed that the primary basis for material segmentation should be amount ordered, why an ABC-analysis was tested - the practical characteristic used became order size, see Flores and Whybark (1986). Creating such a segmentation was hard for Salts as materials had an unstable and disruptive demand structure, why many materials need not be produced in several cycles. In addition, the amount of material needed to be produced would vary greatly between months. This was better aligned with Schonberger (1996), arguing that only materials with sufficient demand should be produced, rendering the segmentation obsolete. In practice, such a solution can be seen equivalent to conducting an ABC-analysis on a monthly basis.

With the discussion on segmentation in mind, the mangers, analysts and researchers concluded that products should be split into (1) materials that should be produced every cycle, and (2) products that should be produced in cases of sufficient demand. By creating such a segmentation, materials with high demand and importance would always be produced, while materials of less demand would be produced when needed.

How Much Material Should Be Produced?

First of all, materials with demand of over one batch monthly, (1), would be produced every month. As for (2), ”size” has to be defined more carefully. The PO, PEN and planners suggested that size best be measured in weight, as materials are sold with similar margin, and capacities over workcentres are similar. Thereby, materials were produced if they constituted high weight in the current month. This in practice could be implemented by enforcing *Minimum Order Quantities (MOQ)* which were already in the system. Customers would order at least the weight suggested by the MOQ, or wait until enough demand had accumulated for production. For materials produced monthly, such a rule is not required, as several streams of demand could fill monthly requirements. Other than the two rules (1) and (2) presented above, an exception was added: free space in the schedule could be used to produce demand under MOQ, to ensure that lines are running.

For long term planning and strategic purposes the forecast already running at ChemCo can be used to predict future production. Having a standardised approach to production, it is easy to estimate schedules and volumes based on such forecast.

As the backlog is sizeable, future capacity increases, or transfers of materials, may become relevant. The simplicity of cyclic production would allow management to easily investigate and evaluate alternatives, as discussed by Chen et al. (2009). This as volumes and schedules can easily be modelled from the forecast.

In What Order Should Materials Be Produced?

As described in the chapter on Salts production, there are (1) inter-batch changeovers and (2) inter-material changeovers. The structure suggested above would mean reduced changeovers for three reasons: (a) larger sequences of batches would be produced, (b) new materials would only be introduced in case of sufficient demand, and (c) materials could be sequenced according to changeovers, thereby relating to both (1) and (2).

A Conceptual Model

The questions answered can be summarised in key findings, presented below.

- The campaign should be planned on a 30-days basis
- Key materials should be produced monthly
- Other materials are produced when sufficient demand exists
- Minimum order quantities are used to ensure sufficient demand
- Free capacity is used for additional demand under the set order quantity
- Capacity is allocated after ”size”, measured in weight
- Materials are sequenced to reduce changeovers

A conceptual model is illustrated in Figure 6.5.2.

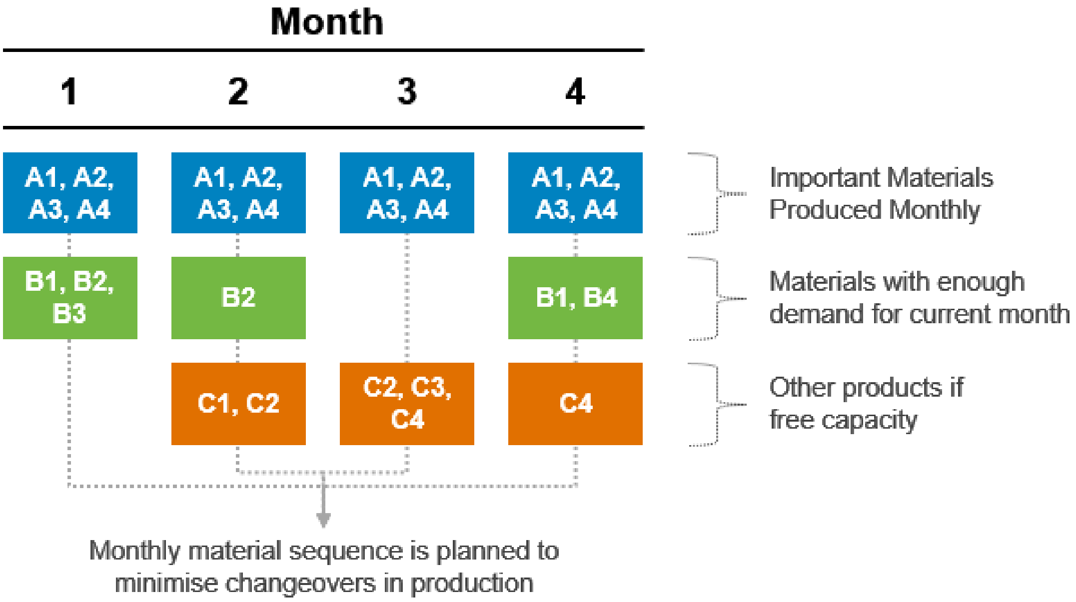


Figure 6.5.2: The conceptual campaign illustrated: key materials are produced monthly, additional materials with enough demand are added, and free capacity is used to fill other demand. Sequencing is set up monthly to minimise changeovers.

6.5.3 Implementing the Production Planning

With the conceptual design of the cyclic process in place, a discussion with the planners and the supply chain managers commenced. The planners mainly wished for a simple tool to make planning more efficient, while the supply chain managers emphasised improved effectiveness to reduce backlog and increase production output.

The researchers had available capacities for SKUs. The PEN provided shortest reasonable campaign lengths for all materials, based on timing required for a full batch. With access to these two sets of data, it was possible to calculate the minimum amount of material demanded for production to be planned during a cycle. Using capacities and suggested minimum campaign lengths, the planners have an easy tool to determine if a material should be planned, using spreadsheet software or even manual calculations. Moreover, MOQs were enforced already in the sales process.

In the model, the 30 day campaign period was allocated into sub-campaigns proportional to the amount of material demanded by weight. Thereby, production time would be justly divided between materials, based on their demand.

With the decisions made, it was clear that the cycle would not be fully standardised, as in the case of Olhager (2016b), but rather approaching a *regularised* schedule, as suggested by Schonberger (1997). Susarla and Karimi (2011) emphasise that plans should be reviewed and updated regularly when using campaign planning, as the production process otherwise tend to become slow and lose agility. Updating the model monthly, as suggested, would counteract such disadvantages, and in addition take into consideration volume changes. To speed up monthly planning, a *Standard Production Sequence* was developed as a visual guide for sequencing.

The production planning process suggested is illustrated in 6.5.3

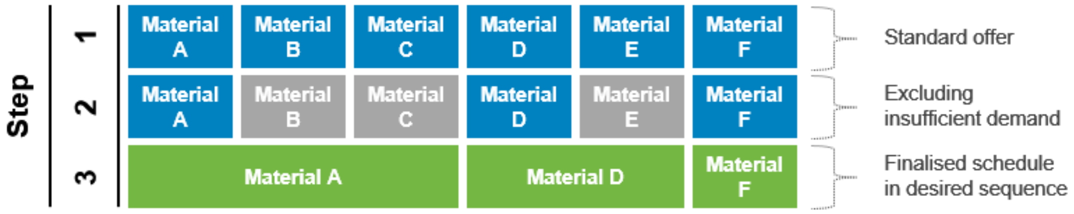


Figure 6.5.3: A visualisation of the production planning process. In the first step, the standard order is shown. In the second step, Only material with sufficient demand is included in the schedule. In the third step, the plan is finalised, producing all material sufficiently demanded in preferred sequence.

Initial Design

The initial large backlog made it impossible to produce all material demanded in a 30 day period. Consequently, the production time needed be allocated. Based on the rules defined above, production time should be split according to amount of backlog. Thereby, material with the most backlog get the most attention. Such an approach would reduce changeover times, as large backlogs would have close to no waiting time or changeovers. *The nature of the system is then that the total output goes up when the backlog is large, and the output of material with high demand or backlog rises,* *counteracting any skewness between materials in the demand.* Notably, running long campaigns of the same material is not associated with the increases in working capital or inventory described by Susarla and Karimi (2011) as all material produced is shipped directly to the customer, it being in backlog.

6.5.4 Responsibilities and Ownership

As per recommendations for establishing new processes in an organisation, clear responsibilities were divided: the PS was given responsibility for evaluating performance of the cyclic production planning, and also the ownership for the project going forward. The planner was given responsibility to use the planning method and adjusting it monthly to plan production. Roles are presented in Table 6.5.1.

Role	**Owner**	**Description**
Executive	PO	Highest manager responsible for the project
Project Owner	PS	Operational project owner and supervisor
Operator	PL:S	Person using the technique operationally
Support	PEN	Support with regards to the plans developed

Table 6.5.1: The roles involved in utilising campaign planning for Salts.

6.5.5 Implementation

The cycle was discussed in the group, whereupon the group agreed that the design was well thought through from all functions. Thereby, the PO decided to implement the design for all workcentres at Salts for two cycles, and thereby evaluate its performance.

6.5.6 Evaluation

This section evaluates the technique developed during the third cycle.

OTIF and Backlog

As for measurements, backlog and OTIF would reflect performance in the long run. Once backlog have been reduced, OTIF will reflect how standardised lead-times will impact delivery performance. However, spurious correlations are expected in the KPIs, as explained in 6.2.2 - *the measurements are secondary.* Backlog could decrease due to decreasing demand, previous spikes in demand or previous machine breakdowns. OTIF could increase due to the backlog decreasing, with no impact from the cyclic planning. The dubious validity of these tests should be taken into account when using these measurements, although they can be studied to reject an performance increase.

OTIF, and backlog were measured the eight weeks before and after the implementation.

Backlog

For backlog development, see Figure 6.5.4.

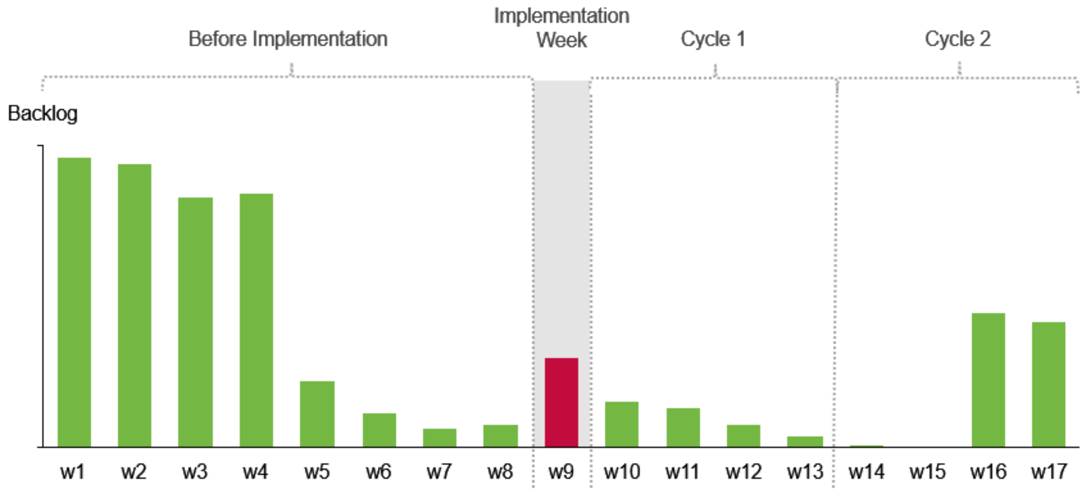


Figure 6.5.4: Illustration of backlog performance over a 16 week period. Actual weeks or numbers are not shown due to confidentiality reasons.

As backlog is a slow moving indicator of performance, measurements are heavily dependent on previous values, making all types of statistical analysis complex or impossible. In addition, certain backlog is expected when a new production technique is implemented, as some materials will get postponed in an implementation.

What can be said is that backlog for Salts have decreased significantly. However, for reasons explained earlier, it is hard to tell whether this is due to the implementation of cyclic planning. It can however be stated that the backlog development does not contradict the hypothetic result suggested by increasing production output.

OTIF

For OTIF development, see Figure 6.5.5.

As OTIF is more momentary than backlog, it makes is simpler to test with statistics. Measuring OTIF performance over 16 weeks, a significance test on the five percent level was constructed to investigate whether the implementation of cyclic planning had affected OTIF performance.

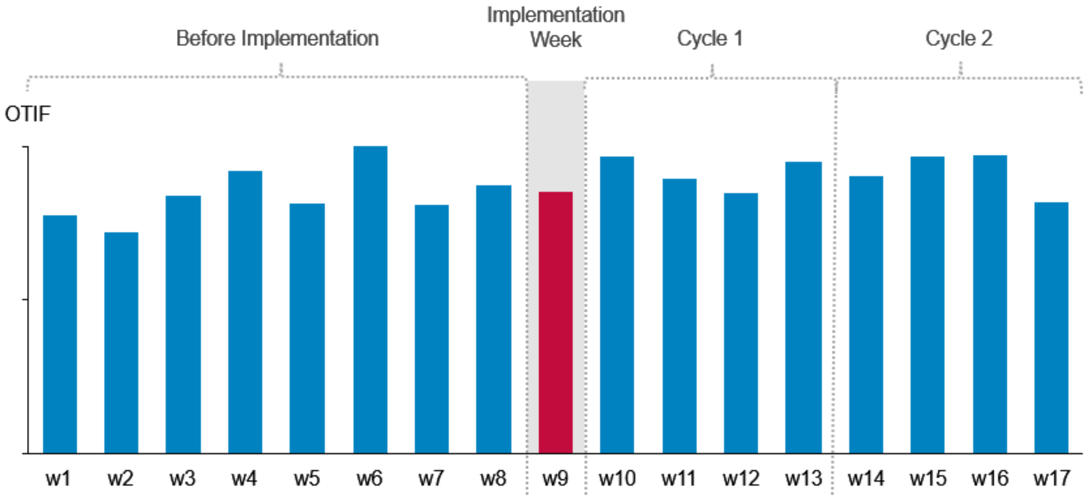


Figure 6.5.5: Illustration of OTIF performance over a 16 week period. Actual weeks or numbers are not shown due to confidentiality reasons.

Hypotheses An initial hypothesis $\mathbb{H}_0$ was constructed:

$$\begin{aligned} \mathbb{H}_0: &\quad \theta_{Before} - \theta_{After} = 0 \\ \mathbb{H}_1: &\quad \theta_{Before} - \theta_{After} < 0 \end{aligned}$$

Where θ_{Before} is the expectation of OTIF before implementation and θ_{After} is the expectation of OTIF after implementation. Should $\mathbb{H}_0$ be rejected, a significant difference between the two expected values is current.

Test The estimate of the expected value, θ^* has the distribution $\theta^* \in N\left(\theta, \frac{s}{\sqrt{n}}\right)$ where s is the estimate of σ. The distribution of the difference between two θ then follows as $\theta^*_{Before} - \theta^*_{After} \in N\left(\theta_{Before} - \theta_{After}, \sqrt{\frac{s^2_{Before}+s^2_{After}}{(n_{Before}-1)+(n_{After}-1)}}\right)$, n_1 and n_2 being the number of measurements of the OTIF.

An interval can be constructed as:

$$\begin{aligned} &(I_-, I_+) = \\ &\quad \left(-\infty, \theta_B - \theta_A + t_{0.05}(n-2)\sqrt{\frac{s_B^2 + s_A^2}{(n_B - 1) + (n_A - 1)}}\right) = \\ &\quad \left(-\infty, 0.7153 - 0.7747 + t_{0.05}(13)\sqrt{\frac{0.0685^2 + 0.0465^2}{(8-1)+(8-1)}}\right) = \\ &\quad (-\infty, -0.0204) \end{aligned}$$

Ultimately, the null hypothesis can be rejected and *a significant improvement in OTIF can be found.* Please note that numbers above are skewed due to confidentiality reasons.

Validity Although a significant difference between OTIF before and after implementation of cyclic planning is shown, it is not possible draw any conclusion about the cause of this change. Looking at the definition of OTIF, as presented in the report, it should be clear for readers that significant differences should not be expected until a full lead-time has elapsed. It can however be stated for sure, that the OTIF performance does not reject the idea that the changed technique indeed increased performance.

Production Output

A better way to measure the impact of cyclic production than KPIs would be to measure the resulting output from the approach. It is known that non-standardised production planning with short production campaigns can negatively affect the output due to substantial time being spent on changeovers (Grunow et al., 2002; Susarla and Karimi, 2011). Ultimately, if the production output increases, with no other changes, the cyclic planning could be credited - the measure thereby illustrating high validity. Increased output in turn would boost OTIF and backlog which are secondary measurements, discussed previously in 6.2.2. Production output does then correlate with the KPIs of the company while measuring the performance of the new cyclic planning. For production output development, see Figure 6.5.6.

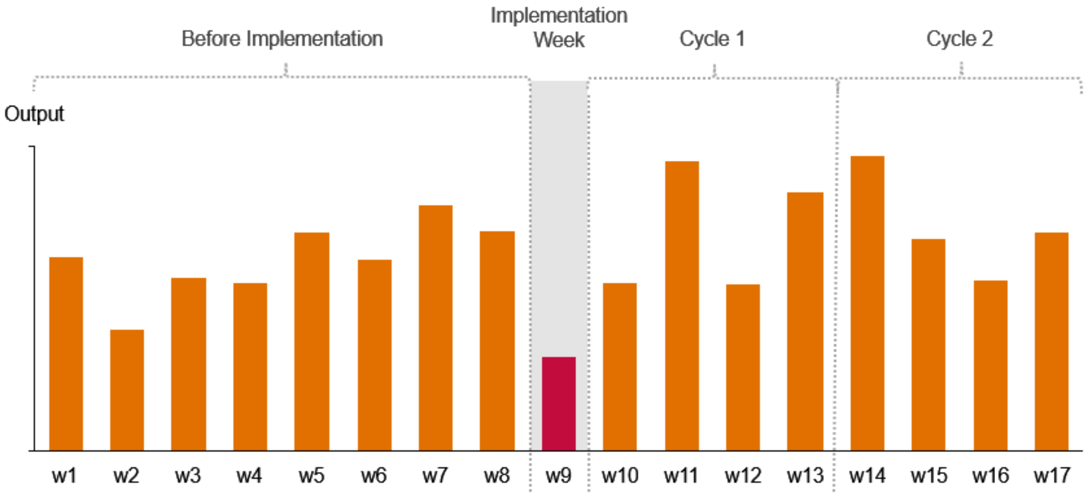


Figure 6.5.6: Illustration of production output performance over a 16 week period. Actual weeks or numbers are not shown due to confidentiality reasons.

Hypotheses An initial hypothesis $\mathbb{H}_0$ was constructed:

$$\begin{aligned} \mathbb{H}_0 : \quad & \theta_{Before} - \theta_{After} = 0 \\ \mathbb{H}_1 : \quad & \theta_{Before} - \theta_{After} < 0 \end{aligned}$$

Where θ_{Before} is the expectation of production output before implementation and θ_{After} is the expectation of output after implementation. Should $\mathbb{H}_0$ be rejected, a significant difference between the two expected values is current.

Test The estimate of the expected value, θ^* has the distribution $\theta^* \in N\left(\theta, \frac{s}{\sqrt{n}}\right)$ where s is the estimate of σ. The distribution of the difference between two θ then follows as $\theta^*_{Before} - \theta^*_{After} \in N\left(\theta_{Before} - \theta_{After}, \sqrt{\frac{s^2_{Before}+s^2_{After}}{(n_{Before}-1)+(n_{After}-1)}}\right)$, n_1 and n_2 being the number of measurements of the output.

An interval can be constructed as:

$$
\begin{aligned}
(I_-, I_+) = \\
&\left(-\infty, \theta_B - \theta_A + t_{0.05}(n-2)\sqrt{\frac{s_B^2 + s_A^2}{(n_B - 1) + (n_A - 1)}}\right) = \\
&\left(-\infty, 91311 - 106043 + t_{0.05}(13)\sqrt{\frac{17173^2 + 23975^2}{(8-1) + (8-1)}}\right) = \\
&(-\infty, -849)
\end{aligned}
$$

Ultimately, the null hypothesis can be rejected and *a significant improvement in production output can be found.* Please note that numbers above are skewed due to confidentiality reasons.

Validity As for production output, as argued above, it is a much better measurement than either of the two KPIs for this project in particular; in fact, it can be argued to be a measurement of high validity. There are however few sources of error to consider. First of all, some lines experienced unwanted downtime during these weeks due to breaks and leakages, which could affect the result, but was not tracked. There also is a slight difference in capacity for different materials, as presented previously, which could affect the result slightly if the same product mix was not produced. Finally, a transfer was tested during the weeks as the result of a strategic decision, which could affect results, although it is added in the total output illustrated above.

As for the statistical analysis, it should be noted that having measured different weeks may have yielded a different result, which comes from using statistics as a tool of measurement. However, the results presented above are reflected by the experienced impact of the team, including all functions. The researchers followed up with one analyst in the final month of documenting the thesis work, August 2016, who expressed that Salts has been doing better.

Revisiting KPIs Once it has been proven that the production output indeed did increase as a result of the new technique implemented, the hypothesis that output would increase KPI-performance can be further validated, although not fully confirmed.

Ultimately, the increased output is expected to reduce backlog, and increase OTIF, compared to the initial situation, as described previously.

Changeovers

One key advantage with the cyclic approach is that changeovers can be optimised on a monthly basis. Although it has been mentioned and argued for several times, the reader should remember it as a key point in evaluating the approach to options.

Efficiency in the Production Planning Process

Discussions with the PS and PL:S concluded that efficiency in the planning process had increased significantly, where the planner suggested that planning Salts was no longer as ”unaided” and complex in periods of backlog. A move from the modification of an MRP-suggested schedule to cyclic planning reduced the time spent planning significantly, while also providing production with a fix schedule for longer periods of time, which was seen as an additional advantage. Moreover, the group overall all mentioned that they had experienced an increase in Salts production output due to the reduction in changeover time, which customers also appreciated.

Strategy Groups

The proposed cyclic technique ultimately is indifferent to what strategy group materials are. However, it can be used to decide on groups. As materials produced weekly are seen as key and important, they could constitute MTSes. It should be noted that these materials could also be MTOs, should there be a guaranteed demand for the full weekly production, perhaps if ChemCo wishes to keep no additional stock for the material - exampli gratia if all volume is sent to one customer. In addition, several materials which today are MTOs can be switched to ATOs, if their ingoing component is produced for other materials - discussed in the second cycle. Finally, materials with low volume being produced in special cases should be MTOs, as the rule for those materials is that they do not constitute necessary volume for monthly production.

For the technique, there are advantages in materials being MTSes or ATOs, as the forecast than could fully be used to also ”forecast”, or prepare, future cyclic schedules, thereby improving delivery accuracy even more, as ChemCo could plan and prepare better for future production.

Lead-times

As presented above, the cyclic schedule would put all regular materials on a 40 days TRLT, should orders not be ”too large”, in which case they are exception orders, or if the workcentre is running on backlog. Smaller orders under the MOQ would have a longer lead-time, although that is expected by customers according to the PO, as they have agreed to that by not enforcing the MOQ.

Looking at the resulting lead-times from this technique in comparison to current levels, it can be concluded that all materials produced internally would have a reduction in lead-time in comparison to current levels.

One comment should be added for MTOs, as the PDT is not included in the 30 days production lead-time that the campaign is based on. Should the PDT be longer than 30 days, it needs to be planned ahead. While that is no problem for MTSs or ATOs, which are forecasted, it can constitute a problem for MTOs. However, no ingoing component could be found with over 30 days of lead-time that is not otherwise stocked.

All lead-times calculated with this technique assume a sufficient demand. This could practically be ensured by implementing a minimum order size, whereby lead-times are valid. For popular materials, the minimum order amount would rarely have to be met since several customers order it, effectively reaching the required demand.

6.5.7 Generalising the Results at ChemCo

Although the process of research and iterating cycles at ChemCo was highly related to the context, the result presented and evaluated is to a large degree generalisable. For firms producing materials with sizeable changeover time, implementing a cyclic production planning, with a set or regularised schedule, could standardise the production schedule, decrease downtime and thereby increase output and simplify lead-times. Ultimately, lead-times can be set in an efficient and accurate manner.

In the case of ChemCo, there were several factors influencing the choice of technique, inter alia the available knowledge. However, the main arguments leading to the cyclic scheduling were ChemCo's notable changeover times, problems with lead-times and fluctuating demand. Thereby, the results are believed to extrapolate well to other firms operating in similar conditions. In addition, the process carried out could provide important advise on considerations and problems in industrial contexts.

General problems with generalisability for action research were countered with the final approach, where validity and reliability could be further ensured due to the introduction of a new measurement, originally not used by ChemCo as a main KPI - although it is tracked on a regular basis. Being able to use that measurement, certain bias was also reduced, or rather nullified, which otherwise could have been a problem as explained in the second cycle. Moreover, the importance of a theory foundation, as stressed in AR, was also a key focus during this research.

6.5.8 Summary

A cyclical production planning technique was developed for ChemCo with a cross-functional team. With the implementation, the production output increased with significance, and several qualitative considerations were in favour of the implementation. Mainly, related to the purpose of this report, lead-times will over time standardise to 40 days, given sufficient demand. Although initial data on delivery performance seem promising, nothing can be definitely said about the impact in terms of the organisations KPIs; it can however be hypothesised that the increase in production output also will affect both key KPIs positively.

The perception of people involved in the production planning process is that the efficiency of the planning has increased significantly. They also feel the downtime due to changeovers have decreased and output increased.

6.5.9 Comments on Action Research

The third cycle included more action than any previous cycle, where actual implementation and operational use of the technique was conducted solely by the responsible parts. Instead, the researchers observed, took field notes and conducted analysis on the technique, why the problem experienced with bias in the previous cycle was not as substantial in the third cycle.

The experienced learning from previous cycle became key not only to come up with the third cycle, but also to develop it in detail, where experience from several functions was needed to design a cycle.

Chapter 7

Conclusion

This chapter will present a concluding summary of the thesis, an evaluation of the fulfilment of the purpose, answers to the research questions, and a concluding evaluation on the methodology chosen.

7.1 Concluding Summary

ChemCo is a high quality producer in the speciality chemical market, operating in an environment where the sought level of quality on products produced results in sizeable changeover times. As demand runs high, inefficiencies and ineffectiveness in production planning led to backlog and decreased production output. Lead-time accuracy has suffered greatly, why ChemCo wished to re-evaluate such times.

In the efforts to find a new method of determining lead-times, a new process for production planning, cyclic production planning, was developed and implemented through theoretical recommendations on campaign planning and cyclic production planning. Literature illustrated that such a methodology could increase production performance. Moreover, the researchers realised that the production planning technique would allow simple rules for determining lead-times in a simple and efficient way.

The resulting method uses demand to determine which materials should be produced in any given month. Materials which qualify for production are produced according to a standardised sequence. See Figure 7.1.1.

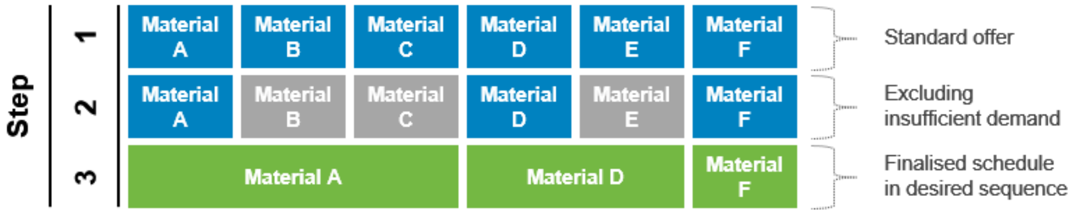
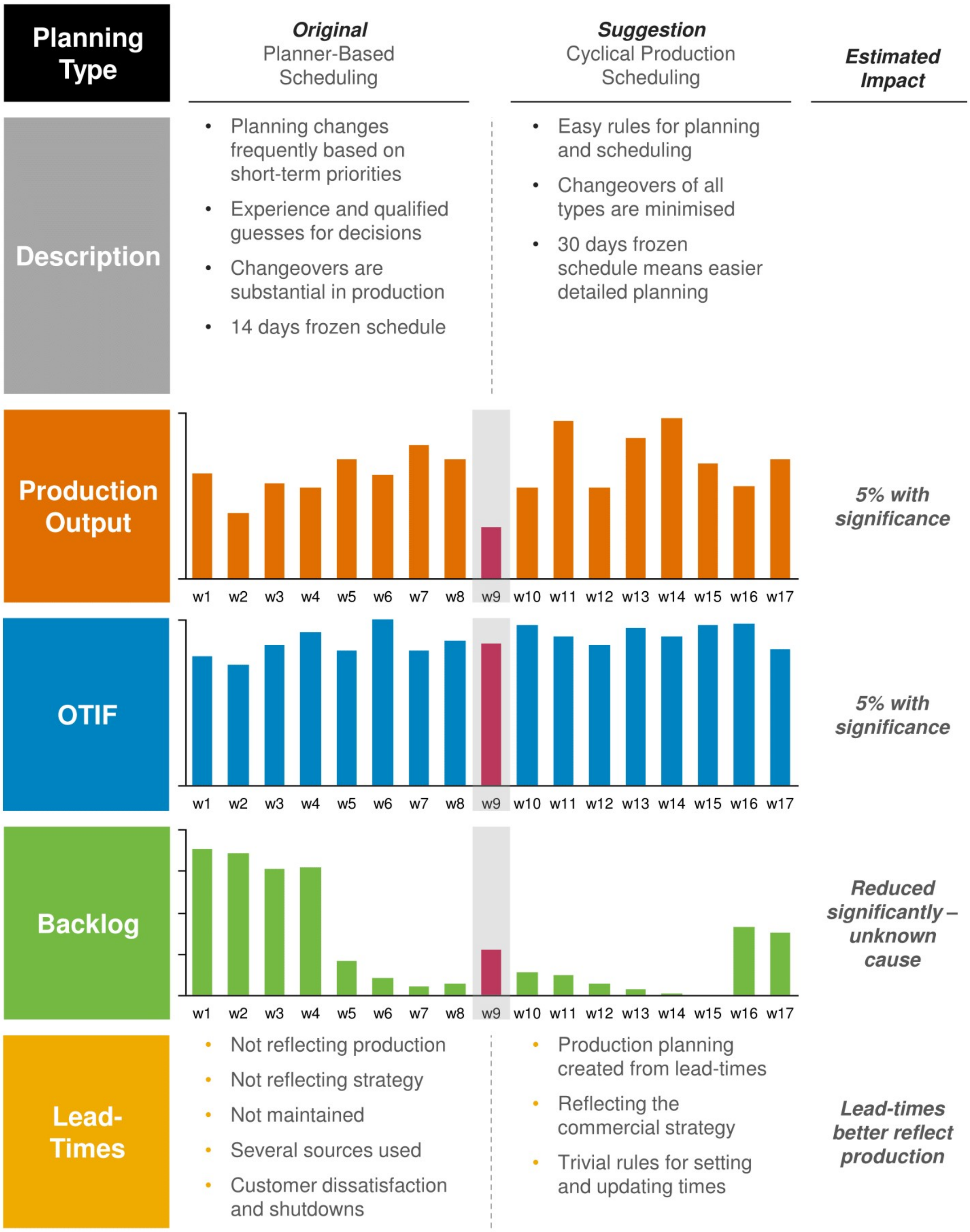


Figure 7.1.1: Revisited: a visualisation of the production planning process.

Early evaluations show an increase in production output, further suggesting an improvement in OTIF. Qualitative evaluations suggest the method will positively affect backlog performance. The reasoning is reflected by reported experiences of the entire team involved across several functions. Lead-times are now determined in a simple calculation, while also having higher accuracy.

Executive Project Summary

An executive summary was created for the project, displayed below in Figure 7.1.2.



Planning Type	***Original*** Planner-Based Scheduling	***Suggestion*** Cyclical Production Scheduling	***Estimated Impact***
Description	• Planning changes frequently based on short-term priorities • Experience and qualified guesses for decisions • Changeovers are substantial in production • 14 days frozen schedule	• Easy rules for planning and scheduling • Changeovers of all types are minimised • 30 days frozen schedule means easier detailed planning	
Production Output			***5% with significance***
OTIF			***5% with significance***
Backlog			***Reduced significantly – unknown cause***
Lead-Times	• Not reflecting production • Not reflecting strategy • Not maintained • Several sources used • Customer dissatisfaction and shutdowns	• Production planning created from lead-times • Reflecting the commercial strategy • Trivial rules for setting and updating times	***Lead-times better reflect production***

Figure 7.1.2: The executive summary from the project carried out at ChemCo.

7.2 Purpose

The purpose of the study is presented below:

This study aims at providing ChemCo with recommendations on feasible modelling of lead-times that is suited for their context.

As the thesis ultimately present a technique for determining lead-times, that are developed through a process of deciding what approach is suited for the organisational context, the purpose can be said to be fulfilled.

7.3 Research Questions

The research questions are summarised below with their answers from the report.

RQ1: How should lead-times be calculated at ChemCo *Salts* production?

Lead-times at ChemCo should be set based on a standardised production cycle of 30 days, and thereafter including 10 days GRT. Given sufficient demand, ensured through minimum order quantities already in the system, the lead-times can be set according to that schedule, and would work should they not be exception orders.

RQ2: What technique should ChemCo use to incorporate such calculations?

The calculations of lead-times have become simple, simply following the campaign time, why calculations are not needed. However, the underlying technique used to assure their accuracy is the monthly updated cyclic production schedule.

RQ3: What impact could ChemCo expect from the developed technique?

Through incorporating cyclic production planning, first the production output is expected to increase. Second, as a result, it is hypothesised that OTIF and backlog thereby also will increase over longer term. Third, the process for for calculating lead-times becomes significantly more efficient. Fourth, the lead-time- and delivery-accuracy should improve, as lead-times are well reflected by production.

7.4 Recommendations to ChemCo

As the perceived benefits of introducing cyclic planning for Salts are sizeable, the performance of the change should be monitored accurately. ChemCo should measure the output of the Salts workcentres to continuously evaluate the methodology. This as key gains from implementing cyclic planning ought to be reduced changeover times, increased production output, and more accurate lead-times, which secondary measurements such as OTIF and backlog do not fully measure. In addition, lead-times should be measured on a regular basis.

Should ChemCo manage to illustrate good longitudinal performance, the cyclic production scheme could be leveraged to other workcentres with similar production characteristics. Should performance not be proven, an evaluation is needed as for why.

7.5 Retrospective Methodology Reflection

This study has its base in an actors view, where a solution cannot be split from the social construction in which it is to be used (Arbnor and Bjerke, 2009; Gammelgaard, 2004). The study has well showed how the future has been constructed from the context, why the approach is seen feasible. Notably, lead-times can be updated through other views, but then putting more emphasis on the objective performance, and less on organisational suitability. The chosen view did extend theory in discussing how and where theory could be applicable.

Action research was selected as the research design, which theoretically suited the chosen view. In practice, AR has shown to be crucial to develop an understanding of the problem at hand, leading to the final solution, but also to develop common knowledge. The iterative nature of research lead to solutions which could not have been reached through positivist means. Research developed over time and was concurrent with action and literature studies, well reflected by theory (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Reason, 1999; Westbrook, 1995).

As for data collection, triangulation has been utilised. Dialogue has been key in collaborative problem-solving (Arbnor and Bjerke, 2009; Voss et al., 2002). However, using dialogue causes certain problems with replicability in the process, why researchers wishing to conduct similar studies are recommended to analogously rely on intimacy - action research is not fully replicable, as it is carried out in a certain context.

The methodology caused certain problems in bias and questions related to validity, which are to be expected from the design and view (Coughlan and Coghlan, 2002; Eden and Huxham, 1996; Voss et al., 2002). As for bias, the researchers had to actively distance themselves from the organisation and reflect upon their role. As for validity, the final solution presented was evaluated through the development of a new measurement, fitting both the context and a positivist view of validity.

Ultimately, the researchers believe that the methodology used in the research has well suited the problem at hand. This is believed to follow as a result of a rigid analysis before the study, which is key for action research. By leaning on theory, but developing an understanding of the context, contributions emerged over time. A final solution was presented that was of practical value to the organisation, managers and employees (Eden and Huxham, 1996; Reason, 1999; Westbrook, 1995).

7.6 Contribution

Below, the expected contribution of this study is presented.

7.6.1 ChemCo

The main contribution to ChemCo is a new technique of planning production for Salts: cyclic production planning. The new technique improves the planning on several points, including output performance and lead-time accuracy.

The technique presented does not rely on a "black box" MRP-calculation, or advanced mathematical modelling, why it is easy to understand for all functions involved, and more efficient to use. The model visualises the production for a month in a clear way, why purchasing and detailed production planning is affected positively.

The increased output from the new technique is wished for given periods of high backlog. In addition, it is believed to improve also the OTIF over time, as lead-times are easier to determine, with a simple calculation as its base, making them more accurate and decreasing the workload for the supply chain team.

7.6.2 Academia

This thesis has contributed to academia in two ways: it has provided (1) a practical use for cyclic production planning in a production environment with sizeable changeover times, and (2) an example of how problems can develop in the given context. The latter also comprising problems which may appear, the skills that might be available, and what an organisation might need.

This research also discussed the implication cyclic production planning could have on lead-times and their performance. Even though much of literature state that standardisation is a key improvement with cyclic production planning, the implications of the standardisations have not been explored to a very high degree.

Ultimately, previous research has mainly focused on validating or calculating lead-times through a positivist approach (Milne et al., 2015). In comparison, this study has treated the problem as an iterative and collaborative problem-solving, putting emphasis on the context and operational characteristics. Furthermore, the study has provided an understanding of how different operational production settings work together, rather than studying them individually. Finally, the recommended solution included an example of developing a KPI that is useful for both academia and the organisation.

Research Suggestions Having developed the practice at ChemCo, there are still questions remaining for future research. Such questions are mainly based on limitations with the study, mainly in terms of available time, and the sample size used. Thereby, studies could answer several questions through a longitudinal study, or through analysing a larger sample size. Example questions are presented below:

- For which companies is cyclical production suitable?
- What is the expected long-term impact for the organisation, both in terms of performance and organisation?
- How does the technique compare to mathematically optimal solutions?
- How does the technique compare to simulation approaches?

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Chapter A

Appendix

A.1 Technical Planning Described

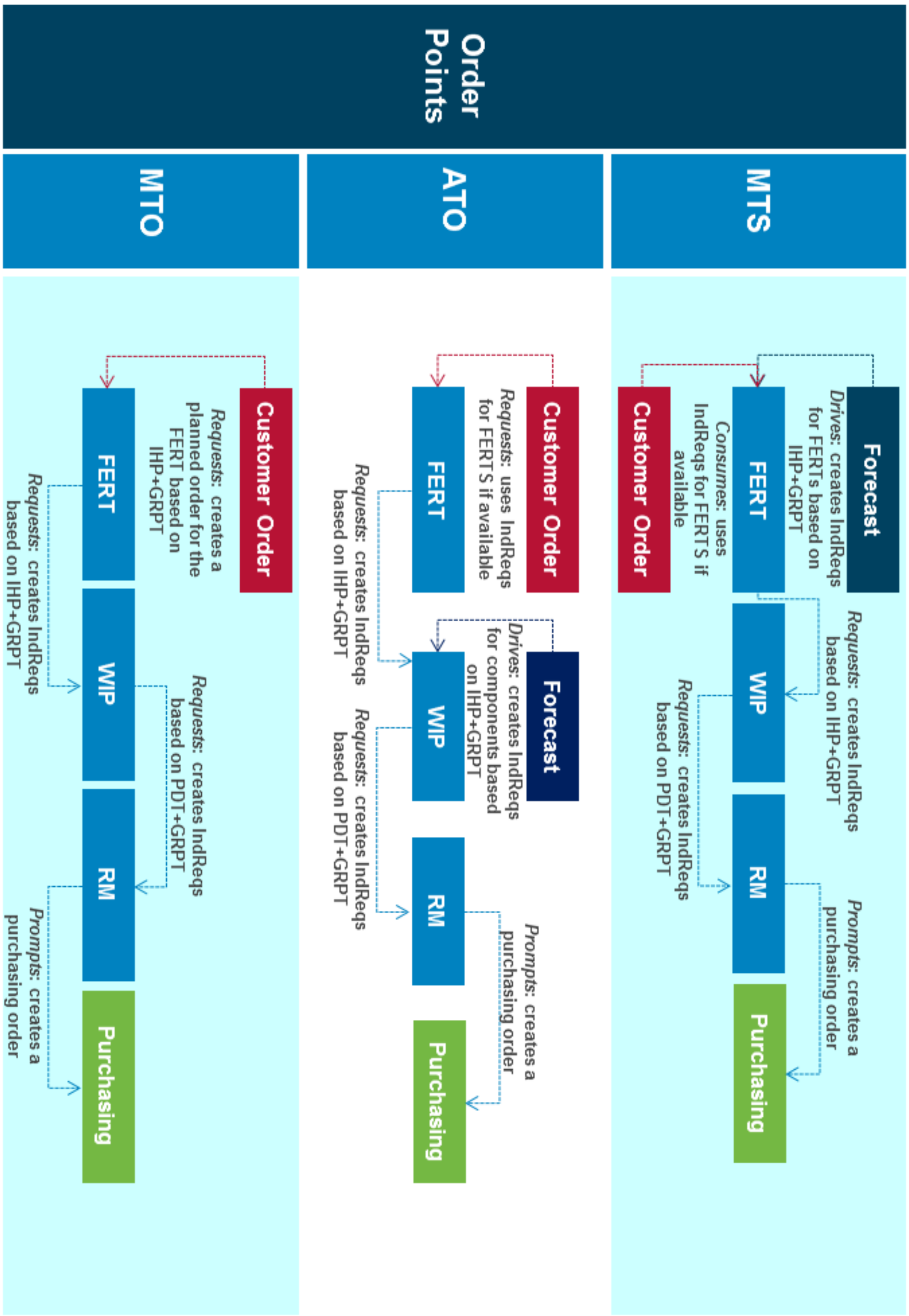

Figure A.1.1: A figure describing the full technical planning process, including how lead-times are related to the steps.