Vertical Collaboration in a Two-Level Supply Chain: An Agent-Based Modeling Approach

A case study on Dreft Automatic Dishwashing Products

By

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Executive Summary

Collaboration in the supply chain is nowadays seen in the scientific community as the "next best thing" in supply chain optimization (Ballot, 2015; Barratt & Oliveira, 2001; Barratt, 2004; Ireland & Bruce, 2000). Although widely investigated and often mentioned in literature, the concept of supply chain collaboration is not precisely defined (Barratt, 2004). It can be roughly described as: collaboration in the supply chain are all the joint efforts of the stakeholders within a supply chain to improve the overall performance(Barratt & Oliveira, 2001; Barratt, 2004).

Procter & Gamble (P&G) can be regarded as one of the largest fast moving consumer goods (FMCG) companies in the world (MBASkool, 2015). Although performing quite well, P&G feels that they can still improve their supply chain (Olsthoorn, 2015). They have expressed the feeling that their main challenge lies in improving their supply chain while being more externally focused (Demange, 2015). P&G have therefore issued this specific project; assessing the effects of vertical collaboration in (one of) their supply chain(s) and provide a handle on how to implement this concept.

This master thesis report discusses the effect of vertical collaboration in a two-level supply chain; collaboration between manufacturer (Procter & Gamble) and the retailer (Retailer X). With the help of a case-study on the product Dreft Automatic Dishwashing (ADW), the goal was to quantify the effect of increased vertical collaboration within a real-life supply chain. To help structure this research the following research question was drafted:

"Could vertical collaboration in the supply chain of Dreft ADW lead to better service, cost and cash results?"

In order to develop an answer to this question, first a literature study was conducted to better define the concept of vertical collaboration. Then, based on a data-analysis on the current state of the supply chain, the problem areas were disclosed for which interventions were devised on the basis of the concept of vertical collaboration. Subsequently, an Agent-Based Model (ABM) of the supply chain of Dreft ADW was designed, to simulate the effects of these interventions so as to provide the data on the effects of vertical collaboration in the supply chain of Dreft ADW. With the aid of the model we were able to both answer the research question as well as to provide the problem owner (Procter & Gamble) an approach to best optimize their supply chain by using the concept of vertical collaboration.

The interventions that were used to embody the effect of vertical collaboration and subsequently tested in the ABM were:

- Production batch size alignment to retailer orders.
- Alignment of order information sharing process between retailer and manufacturer during promotions or continuous interaction.
- Use of real-time up-to-date information throughout the supply chain in ordering and replenishment.
- Use of POS data in the ordering and replenishment process.

The results of the model show that vertical collaboration in the supply chain of Dreft ADW could indeed lead to better service cost and cash results. By implementing the interventions in four sequent steps, service levels can be increased without increasing inventory levels. Next to that, cost savings of up to ***2.4%*** of the gross value of the sold products can be achieved.

Preface

This master thesis is the final project of the Master Management of Technology. It is my very last project as a TU Delft student and will (hopefully) deliver me title: “Master of Science in Management of Technology”. However, it can be said that it has been quite a journey for me to get to this stage.

This journey started at the end of academic year 2012/2013, when I decided I wanted to do a double degree. I had already started my Master study in Chemical Engineering earlier that year, but then I came across a double-degree program offered by the faculties Applied Sciences and TPM. No sooner said than done, I enrolled in the program and started my second masters in Management of Technology. After 1.5 years of courses, assignments and reports (even another master thesis), I came to the point that I needed to orient myself on what the subject would be of this thesis. But how, or moreover, where to start?

One thing I knew was that I wanted to graduate at a company. During my (at that point in time) 6.5 years of study, I had never seen a company from the inside. Therefore I wanted to experience working at a real company during my thesis, so I would know what to expect when I enter the labor market. Next to that, I knew that I wanted to graduate in the field of supply chain management. Although I did (at that point in time) not have any background in the field, I knew that I liked the socio-technological side of the matter (as I am still an engineer). Keeping these two demands in mind, I set out to find a suitable graduation project.

Luckily I did not have to look very long or search very hard. Via a friend of mine I applied for the master class of Procter & Gamble, for which I was ultimately invited. During the master class it became clear to me that Procter & Gamble was able to offer (graduation) internship projects. To make a long story short, I ended up at this great company, with this fun project on collaboration in the supply chain. Although I will not go into any details about the project itself (these can be found extensively in the rest of this report), I do want to thank a few people that helped me during this project.

First of all, Yannick Vergouwen, my supervisor at Procter & Gamble. Who, while having a very busy schedule, always found the time to guide and help me with my project. I think I can honestly say that I would not have been able to bring this project to a successful end without your help! Next to that, thanks to Marcel Ludema, for his guidance at the university and numerous meetings that helped me improve my thesis work. Also, thanks to Michel Oey, who, in the few talks that we had, always provided me with valuable feedback on both my computational modeling and overall direction of the project. Last but not least a special thanks to Lori Tavasszy, the chair of my graduation committee, who especially helped me in defining the scope of my project.

Besides the members of my committee I would like to thank all the people at Procter & Gamble that helped during my project, but more importantly helped me have a good time in the office. Thanks go to my family and friends who helped and supported me during the course of the project. Meke, for providing feedback upon my work. Special thanks go to my parents for supporting and encouraging me to do a double degree program and to Aafke for her love, support and critical (but very useful!) notes on my presentation slides.

Pieter Braams
Delft, 15 January 2016

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1. Introduction

Procter & Gamble (P&G) is currently one of the leading companies in the Fast Moving Consumer Goods (FMCG) industry (MBASkool, 2015). Examples of P&G's leading position are:

- P&G owns and brings to the market over 300 brands (e.g. Gillette, Ariel, Dreft, Olaz, Pampers etc.) in over 50 product categories (Procter&Gamble, 2015a).
- P&G products are being sold in over 180 countries and P&G operates as a company from over 80 countries (Procter&Gamble, 2015a, 2015b).

However, in order to keep its leading position in such a fast changing industry, P&G needs to keep innovating and improving their business. The Supply Network Operations department of P&G has identified three main goals that give direction to the business to help compete in this competitive industry (Olsthoorn, 2015). These goals are:

Examining the existing literature on "supply chain collaboration", the concept can be traced back to the late 1980's when the first research projects on the subject were launched (Skjoett-Larsen, Thernøe, & Andresen, 2003; Zhou & Benton Jr, 2007). Then started two decades of research- and pilot projects to get a better grasp on supply chain collaboration and what it (should) entail(s). A broad literature overview on the concept is provided in a separate chapter of this report, but the immediate question arises: is the topic still relevant in the current day supply chain?

Although supply chain collaboration in its earliest form originates two decades ago, the concept has enjoyed renewed interest by the scientific community over the past few years, due to the introduction of the Physical Internet (Montreuil, 2011). The idea that made its first entrance in the late 2000s and is based on the digital internet (hence the name Physical Internet) (Montreuil, 2011). It is defined as *"A global logistics system based on the physical, digital and operational interconnectivity enabled by smart modular containers, interfaces and protocols for increased efficiency and sustainability",* the Physical Internet (PI) can be envisioned as the Holy Grail in freight transport (Ballot, Montreuil, & Meller, 2014; Montreuil, 2011). One of the key pillars of the Physical Internet is collaboration between the various actors within the supply chain; bridging both interest of P&G and current research of the scientific community.

It can thus be seen that collaboration in the supply chain has been around for quite a while and has gotten renewed interest both in the scientific community and the business world. In light of the research on using the benefits of collaboration in the supply chain; Procter & Gamble together with Retailer X launched a supply chain improvement program in which subsequent steps would be taken to collectively optimize the supply chain. The figure below shows the steps that form a pathway to an optimal performing supply chain between both parties. The same figure also shows the current state of the collaboration project and which steps still need to be taken. The next step in the program is a combined value chain analysis on the supply chain between Procter & Gamble and Retailer X.

With a value chain analysis as the next step, Procter & Gamble has issued this specific research project to gain a quantitative insight of the effects of using the concept of collaboration between them and Retailer X on the current supply chain. A value chain analysis (outside the boundaries of the firm) would provide the needed information on *where* to improve the supply chain (Hines & Rich, 1997). Applying the concept of collaboration would be the tool that should be used on *how* to improve the supply chain. The most straightforward way to gain this knowledge is the use of real-life pilot projects (creating collaboration in the supply chain and measure what its effect is in real-life). However, these projects are often costly and time consuming. A cheaper alternative is the use of computer simulations to test the effects of collaboration in the supply chain.

Therefore it was chosen to perform a modeling (or simulation) case-study on a product that is produced by Procter & Gamble and sold by Retailer X (therefore moving through the supply chain of Procter & Gamble and Retailer X) to quantify the effects of collaboration in this specific supply chain. The chosen product associated to such a chain concerns Dreft Automatic Dishwashing (Dreft ADW). The reasons why this product was chosen and other choices on modeling techniques is discussed in a later chapters.

In the remainder of this chapter we will provide background information on the supply chain of Dreft ADW, the scope of the project and the research problem. Chapter 2 will give a research overview with inter alia the research questions and methodology. Chapter 3 will give an overview of the relevant literature. Chapter 4 provides an in-depth analysis on the current state of the supply chain. In chapter 5 a stakeholder analysis is done, chapter 6 provides the reader an insight in modeling design choices and chapter 7 through 9 discusses the outcome of the computer modeling. Chapter 10 and 11 will provide conclusions and recommendations of the research and finally, chapter 12 will show the authors personal reflection on the project.

1.2. Background information on the supply chain of Dreft ADW

This section will give an insight in both the current supply chain of Dreft ADW, its choice for an end-to-end supply chain, as well as the future state of business which the supply chain should comply to and the issues that arise with adaptation to this future state.

Current Situation

In the description of the current situation, topics like the overall status of the supply chain, a stakeholder overview, the product flow and the information flow will be discussed.

The Supply Chain of Dreft ADW

Looking at the current state of the supply chain, it can be observed that the supply chain can be divided into 3 parts; each with a different controlling actor. Figure 2 shows a global overview of the supply chain. In the figure the overall supply chain, the product flow, the information flow and controlling actor are depicted.

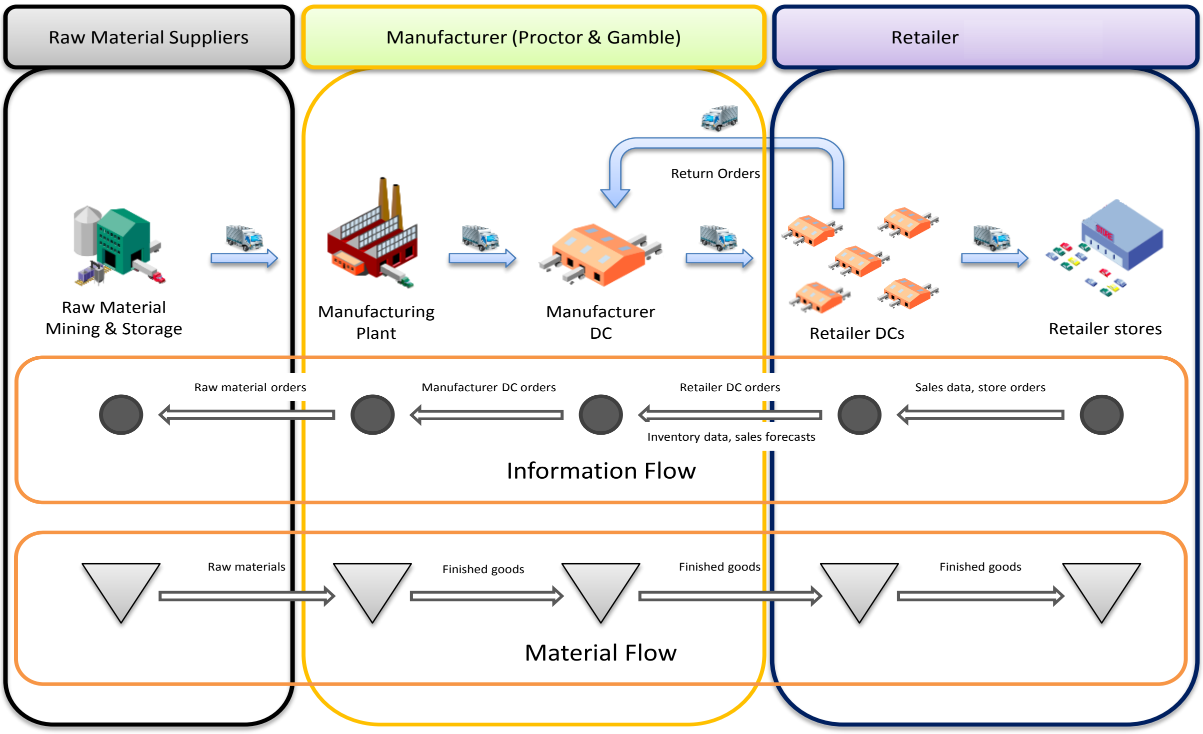

Figure 2: Current state of the Dreft ADW supply chain

A classical supply chain usually consists of three actors: a (raw material) supplier, a manufacturer (of finished goods) and a retailer (of finished goods). In such a supply chain each of the actors takes care of its own part of the supply chain and strives for optimization. This means that the supplier of raw materials makes sure that demand from the manufacturer is being met. On his turn the manufacturer makes sure he meets demand from the retailer, who subsequently serves the consumer in its product needs. However often in these kinds of supply chains, almost no or very little collaboration outside the boundaries of a company takes place.

Although the figure is a global overview, it does provide us valuable information on the demarcation and scope of the project. Where a classic description of a supply chain consists usually of three (or more) unidentified actors, this figure identifies two of these actors by name; the manufacturer (represented by

Procter & Gamble) and the retailer (represented by Retailer X). This (in a nutshell) provides the scope of this research; collaboration in the supply chain between manufacturer and retailer (a two-level supply chain) by performing a case study on Dreft ADW for Procter & Gamble and Retailer X.

As stated in the introduction that Procter & Gamble measures the performance of their supply chain according to three different key performance indicators (KPIs) (Olsthoorn, 2015):

An in-depth current state analysis on these KPIs is discussed in chapter 4, but a quick look at the target levels and balance between these three KPIs shows that especially service does not meet the standard. This creates an undesirable (and probably needless) pressure on the Supply Network Operations (SNO) department of Procter & Gamble.

An initial analysis on the root-causes of this service level problem has shown that the main cause is the lack of information throughout the chain (a complete overview of the root-causes is given in chapter 4). Especially when large volumes are being sold, high deviations from forecasts causes problems upstream in the supply chain. Communication and information sharing within and between the actors can thus be seen as one of the prominent problems of the current state of the supply chain. Collaboration embodied in more communication and information sharing between Procter & Gamble and Retailer X might therefore be the optimal tool to create a better performing supply chain.

Supply Chain Stakeholders

In the overall P&G supply chain there are several actors that take part. These actors and their roles are shown in Table 1**.**

Table 1: Stakeholder overview

Actor	Role
Procter & Gamble	Is the manufacturer of Dreft Automatic Dishwashing and sells them to the buyer
	Is the retailer; buys Dreft ADW from P&G and sells it to the consumer
Raw Material Supplier	Supplies P&G with raw materials to produce the finished products
Trucking Company	Arranges transport from supplier to plant, plant to DC, DC to DC and DC to store (varies per route).

As stated earlier, in this research the focus lies on the first two actors. These two actors have both shown the willingness to cooperate in the project and are moreover able to provide the needed data to perform a value chain analysis.

Product Flow

Figure 2 also gives a schematic representation of the physical product flow. As the scope of this project is Dreft ADW, the physical product that eventually ends up on the shelf in the retail stores are the actual packages with Dreft ADW patches. There is a wide variety in sizes, colors, scents etcetera, but currently a grand total of approximately X cases per year are sold, which loosely translates to X million bags per year of Dreft ADW that are shipped to Retailer X. This indicates the large volume that needs to be shipped throughout the Netherlands annually. Because in the remainder of this report a variety of terms will be used to describe the selling/transportation/production amounts, the table below will provide an overview of these selling units and the relationships between them. An detailed overview of the complete flow of materials is given in chapter 4.

Table 2: Overview of the various units of Dreft ADW used in this thesis

Name	Amount	Picture
Patch	1 dishwashing tablet	
Bag	Between 12-30 patches/bag (dependent on bag size)	
Case	5 bags/case	
Pallet	Approximately 100 cases/pallet	
Truck	33 pallets/truck	

Information Flow

As already briefly touched upon in previous sections, the current flow of information can be divided into three distinct sections; the information that is in possession of 1. the retailer (RETAILER X) 2. the manufacturer (P&G) and 3. the raw material supplier. The figure below shows the actors and the pieces of information they have in the supply chain.

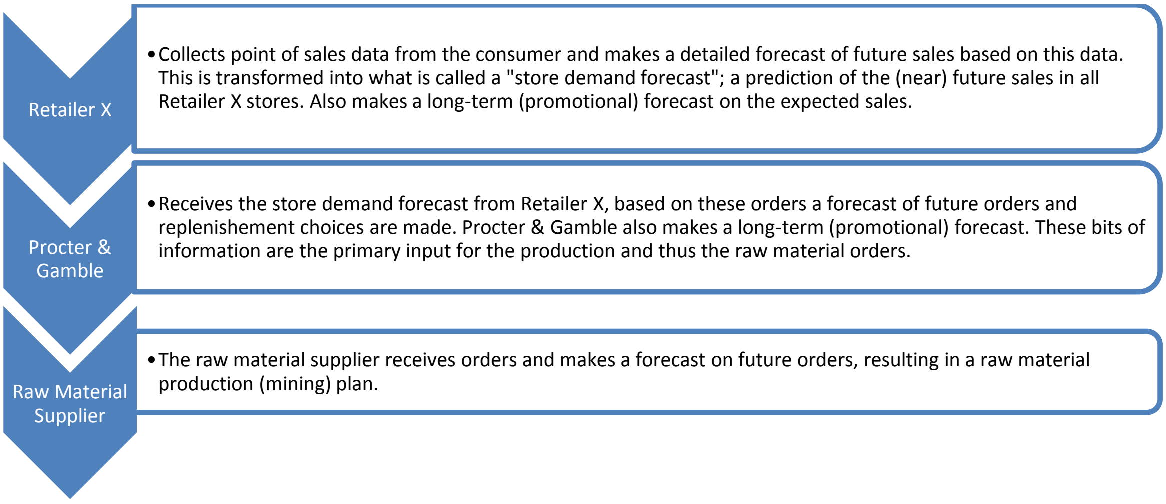

Figure 3: Flow of information

Again, the main focus here lies on the first two actors and the information they share with each other. A detailed overview of the complete flow of information is given in chapter 4.

Desired Future State

In the current field of supply chain management research, companies have started to realize that it is not optimal to tweak (part of the) supply chain, but more valuable to rethink it end-to-end (Lee, 2010). This line of thinking has been picked up Procter & Gamble and they have expressed the feeling that a competitive supply chain should be focused on collaboration between companies within the supply chain instead of only optimizing their own part. For the Dreft ADW supply chain, this indicates that both the raw material supplier and retailer should be incorporated in the supply chain practices. The question that should be asked when identifying changes and optimization steps in the supply chain is: *"What would be different when the Dreft supply chain was managed by one company?".*

To identify these possible changes in the current state of the supply chain, a time horizon needs to be set. A good time horizon can provide the basis for changes within the external limitations that are applicable to that time and provides a better scoping of the project. This research project on Dreft ADW is issued by Procter & Gamble as a pilot to generate insights that can be applied to other supply chains. Therefore, there is the project's desire to provide concrete and tangible changes in the supply chain in present-day times, while keeping an eye on the future. For example, proposing changes in the current infrastructure (new warehouses, new plants) or preparing for the extinction of the dishwasher are not desirable, but anticipating on developments in information technology (RFID, cloud computing etc.) and changes in views on collaboration between companies is expected. It is therefore chosen to define the time horizon to be a supply chain in the year 2020. By that time, improvements in IT might have occurred and thoughts on collaboration in the supply chain might have radically changed. However, changes within current the physical infrastructure would have not happened yet. Therefore a scenario analysis is done for the supply chain of Dreft ADW in the year 2020 to identify the possibilities for change within the time framework.

Scenario Analysis

Scenario analysis, or scenario planning, is a tool that is used for creating a future context that functions as a basis for companies to make long-term plans (Wilde, 2000)**.** The intention of scenario analysis is not to *predict* the future, but to provide a *forecast* on the future; as predictions are based on supernatural gifts or abilities and often do not work out. It is a means to forecast any possible future situation as to make the problem owner (Procter & Gamble) conscious of the uncertainties in its policy design. In a scenario analysis, often many different (parallel) future situations are sketched.

In this research a scenario analysis is performed to create a context for the Procter & Gamble supply chain in the future on which supply chain design choices can be made. Within these scenarios, the focus lies with the developments and innovations in the field of logistics and supply chain management. Disruptive innovations in the dishwashing industry (e.g. innovations and trends that eliminate the need for dishwashing machines) are chosen to be out of scope, as these changes would eliminate the need of the supply chain altogether.

Scenario analyses have been performed by various companies in various fields of research (Wilde, 2000). Interesting research has been done by DHL, PriceWaterhouseCoopers and others to sketch the logistics and transportation industry in 2030 and 2050 (DHL, 2015; KPMG International, 2014; Ruske et al., 2009). Moreover companies like KPMG and Ernst&Young have analyzed how megatrends might influence and shape the global future (Chatterjee, Küpper, Mariager, Moore, & Reis, 2011; Ernst&Young, 2015; KPMG International, 2014).

Although the scenario analysis (as shown in Appendix C: Scenario Analysis) does not have a central role in this research, it might give the reader some interesting back-ground information on the future of supply chain management. Next to that it provides the link to an up and coming concept in the scientific community; the Physical Internet (Ballot et al., 2014). This is a concept that has been around for a few years, but is only now starting to gain more attention (Ballot et al., 2014; Ballot, 2015; Montreuil, 2011).

The Physical Internet

Defined as: "A global logistics system based on the physical, digital and operational interconnectivity enabled by smart modular containers, interfaces and protocols for increased efficiency and sustainability", the Physical Internet (PI) can be envisioned as the Holy Grail in freight transport (Ballot, 2015)**.** In short, the Physical Internet is a concept that pictures the global logistic network as a network of smaller logistics network of individual actors. It heavily relies on the collaboration between companies (integrated decision making in end-to-end supply chains) and technological advancements (IT improvements and container standards within logistics networks) (Ballot et al., 2014; Ballot, 2015; Montreuil, 2011). Appendix A gives additional information on- and a more in depth description of the Physical internet.

Although the Physical Internet itself is a much too broad and extensive concept for a master thesis research, one of the key pillars (collaboration) to ultimately reach this desired state of supply chain execution is suitable for such a research. Keeping this in mind, the desired future state of the supply chain of Dreft ADW should be a supply chain with improved collaboration that provides a first step towards a Physical Internet and improves the overall supply chain performance.

The Future Supply Chain of Dreft ADW

By performing a scenario analysis we have acquired an understanding of how the future will look like and what prospective factors will play an important role. If one believes that the Physical Internet will indeed be "the next best thing" in supply chain management and innovation, it will be the task of this research to see what will happen with the supply chain of Dreft ADW in such a scenario.

As Procter & Gamble has also expressed that they feel the need to improve the supply chain in collaboration with the customer, an optimal future supply chain of Dreft ADW (within the scope of the project) is a supply chain where Procter & Gamble and Retailer X fully collaborate to ensure the best possible performance. In doing so, it will prepare Procter & Gamble for a future where a Physical Internet is in place.

What is however optimal? How can collaboration between Procter & Gamble and Retailer X help to solve these problems? What are the specific changes to the supply chain that need to be put in place? How can we measure whether these changes are effective? These questions are only a few examples of the questions that arise when setting up a design project of such a supply chain. However the most prominent and vital question for the problem owner to ask oneself is, what is/are the current problem(s) in the supply chain of Dreft ADW?

1.3. Research Problem

As described in the introduction, Procter & Gamble has three pillars on which they focus to be competitive and keep profitable in the FMCG industry. These three pillars are: guaranteeing top service, generating costs savings and increasing their cash. Although acknowledging the importance of a good balance between these three, the current balance between these three pillars is not optimal according to Procter & Gamble (Demange, 2015; Olsthoorn, 2015).

the supply chain anymore. An initial research has shown that a lack of information sharing between the retailer and manufacturer might have resulted in the low service levels. This is in line with previous research, that has shown that information sharing increases supply chain performance (Barratt & Oliveira, 2001; Croom et al., 2007; Zhou & Benton Jr, 2007). With consumers becoming more demanding in the future, resulting in higher strains on the supply chain, Procter & Gamble must leverage the possibilities to integrate their supply chain with retailers to stay competitive in the future.

This project will therefore investigate the concept of collaboration in the supply chain. Central in this research will be the sharing of information/data throughout the first two actors in the chain, to minimize the distortion in the flow of information. The objective of this research will therefore be:

“Develop a tool to measure the impact of collaboration in the Dreft ADW supply chain KPIs”

The research design as described above is a clear example of a description of a possible future scenario if/when something changes in the current day practices in a complex adaptive system. It is a design of an exploratory research that tries to answer certain *“What if….?”* questions for future situations (e.g. what if there is complete collaboration in the future of the supply chain). According to Van Dam, Nikolic and Lukszo (2012), a suitable method to design a tool that could do such a thing would be Agent-Based Modeling (ABM). They described agent-based models as tools to *“discover possible emergent properties from a bottom-up perspective”*. Although it is not (only) about discovering these properties in this case, ABM can also be a suitable tool to investigate what it takes to make something specific happen. For example; the improvement of the supply chain KPIs in the case covered in this research. A broader disquisition on possible other methods of modeling is given in a later chapter; when we are deciding upon a modeling tool.

The research will focus on a two-level supply chain: a supply chain consisting of the retailer and manufacturer. Although not really a “supply chain” (as it only incorporates two levels), in the remainder of this research the case study on these two levels will be referred to as: “the supply chain”, or “supply chain of Dreft ADW”. Agent-based modeling has been used in supply chain modeling before, but mainly focusing on agents within one of these actors (the manufacturer) (Julka, Srinivasan, & Karimi, 2002; Min & Zhou, 2002; Van Dam, Nikolic, & Kashmire, 2012). This research will therefore incorporate both the interactions of agents within the actors as well as the interactions between the actors. As stated before, the research will be a case study on Dreft ADW, which is produced by Procter & Gamble and sold to the consumers by Retailer X. The point of sales data is generated by the consumers of Retailer X stores, which currently also includes on-line stores, as these have the same supply chain practices.

2. Research Approach

In this chapter an overview of the research is given. The observed research problem, the core research question and the thesis framework and methodology will be discussed.

2.1. Core Research Question

As stated in the research problem, the service levels of Procter & Gamble do not meet the requirements set by their customer Retailer X, as can be concluded from the supply chain data. However when one digs a little deeper (as extensively shown in Chapter 4), it turned out that one of the main problems was the lack of collaboration in the supply chain. Subsequently, the central question within this research arises.

"Could collaboration in the supply chain of Dreft ADW lead to better service, cost and cash results?"

The central research question can be divided into several sub questions that all address a specific part of the core research question.

1. What is the current flow of materials and information and what are the various stakeholders in the supply chain?
2. How the supply chain KPIs measured and what are their current states?
3. How is collaboration in the supply chain defined?
4. What are future scenarios concerning collaboration in the supply chain of Dreft ADW?
5. What is the quantitative impact of these future scenarios on the supply chain KPIs of Dreft ADW?
6. What software package/tool must be used to model the supply chain?

The first two sub questions focus on the current state of the supply chain. The third sub question will focus on making a generic definition on collaboration in the supply chain. The next two sub questions focus on how to measure collaboration in the (case-specific) Dreft ADW supply chain and the impact that the predefined concepts of collaboration will have on the overall performance of the supply chain. The last sub question addresses the choice of the modeling tool. What method and software package do we choose to model the supply chain with? The thesis framework and research methodology behind each sub question will be discussed in the next sections.

2.2. Deliverables & added value to the current field of research

Based on the above methodology, a few deliverables can be identified for this research project:

1. A model that uses collaboration in the supply chain of Dreft ADW to measure the impact of collaboration on supply chain KPIs.
2. Advice on practical improvements in the supply chain of Dreft ADW, based on various experiments.
3. A research report.
4. Final presentation for the supervisors and those interested.
5. Final presentation with supply chain recommendations for the management of Procter & Gamble and Retailer X.

2.3. Thesis Framework

The figure below gives an overview of the thesis framework. It consists of 3 phases:

- Analysis phase: the goal of the analysis phase is to identify the current state problems of the supply chain and how to use collaboration in the supply chain to solve them. By performing a literature research, supply chain mapping and a scenario analysis a future design of the supply chain will be made that can be translated into a computational model. The chapters 3 through 6 describe the analysis phase
- Modeling phase: this phase entails modeling of the current supply chain and the validation and verification of this model. This model will subsequently be used to test future supply chain scenarios with more collaboration in the supply chain. Chapter 7 describes the modeling phase.
- Experimentation phase: in this phase, experimentation with the model is done. Experimentation with the, in the analysis phase designed, future scenarios with collaboration in the supply chain, will provide insights in the effect of this collaboration. Chapters 8 and 9 give an overview of the experimentation phase.

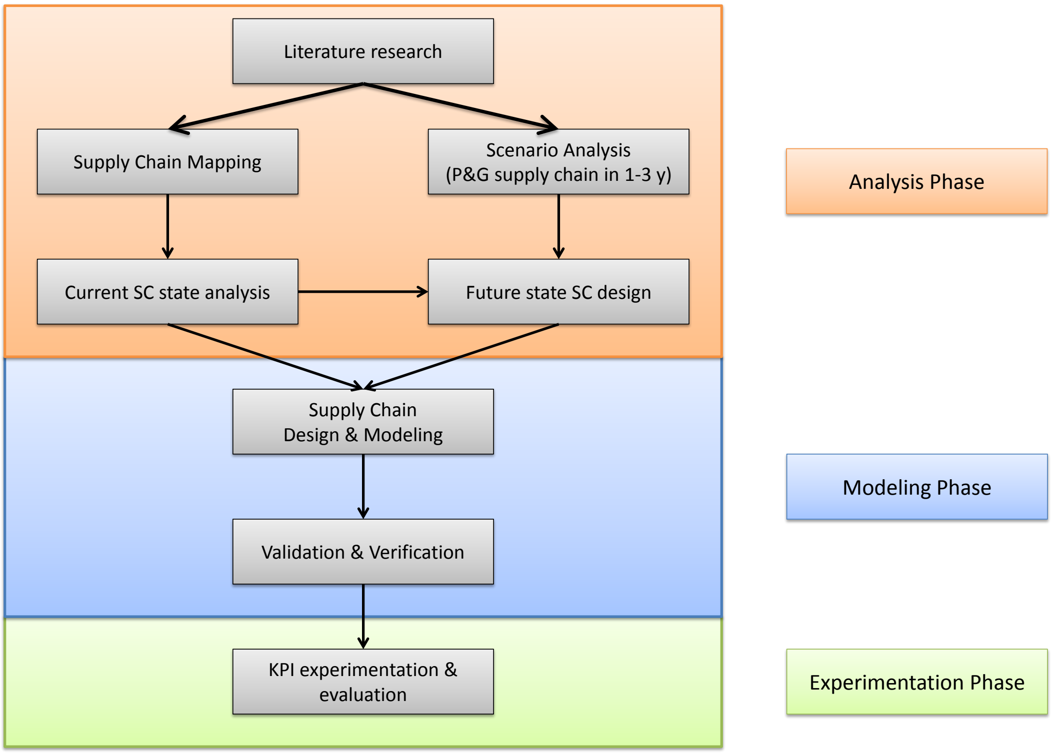

Figure 4: Proposed research framework

2.4. Methodology

In this part the methodology for answering the research question(s) will be discussed.

Main Research Question

The main research question is a question that can be regarded as a typical operations research problem. As mentioned above, this research is aimed at providing a sustainable and optimal solution to the problem of low service levels (SAMBC levels) by increasing the collaboration in the supply chain. Next to that, this research aims at quantitatively determining the effect of collaboration in the supply chain through information sharing. Therefore the Operations Research methodology will be used as a framework for the complete project (Eiselt & Sandblom, 2012). The general methodology is shown in Appendix B, just as the methodology applied to this research.

Sub questions 1 and 2

The first two sub questions will be answered by conducting a case-study on the current state of the Dreft ADW supply chain, consisting of an observation of what is happening in the supply chain without interfering. A case-study is chosen, because of the three reasons mentioned by Fidel (Fidel, 1984). No hypothesis is made on how the supply chain will look like, but rather the material and information flow in the supply chain will be observed and mapped. The relevant data will be collected in the following way:

- Talking to experts within the supply chain of Procter & Gamble *(information flow/agents/KPI determination)*
- Talking to experts of Retailer X *(information flow/agents/KPI determination)*
- “Field research” and observations throughout (the larger part of) the supply chain *(material flow/information flow/agents)*
- Previous research projects/literature *(material flow/information flow/agents)*
- Data centers of both Retailer X and Procter & Gamble *(material flow)*

After the right data is collected and the sub questions have been answered, it will be used for both designing the modeling tool and for validation and verification of the tool.

Sub questions 3, 4 and 5

To be able to answer the next three sub questions an experimental approach will be used. First, with the help of a literature study, we need to identify how best to define collaboration in a generic way. Once we have defined collaboration and identified its most important variables, experiments will be designed to quantitatively measure their influence in the (in sub question 3) determined KPI’s, thereby (quantitatively) measuring the effect of collaboration. Testing of the experiments will be done in a computer model designed from the input of sub questions 1 and 2, in a software package defined in sub question 6.

Following the findings on these three sub questions, the main research question can be answered. Subsequently, advice can be given on the optimal design of the supply chain of Dreft ADW. The steps can be summarized as followed:

- Concrete definition of collaboration based on literature
- Design of a (computational) model to quantitatively test the influence of the variable on the predefined KPIs (based on supply chain data analysis and previous research)
- Testing the experiments in a computational model, build in the chosen software package
- Validation and verification of the outcome of the experiments (with the help of case-study data, literature and industry experts)
- Evaluating main research question

Sub question 6

The desired outcome of this question is to identify a suitable software package in which the supply chain can be modeled.

- With the help of a literature study the method of modeling will be identified.
- After this step, previous research and expert opinion will be used to identify the right software tool for this kind of research.

3. Literature Research

In this chapter we will give an overview of the literature research that was done for this thesis. The goal of this literature research was threefold:

- Identify possible ways to map and measure the current state of the supply chain.
- Define the concept of collaboration in the supply chain.
- Identify the right method of modeling.

Given these three objectives, we set-out to find a the relevant scientific articles to give academic body to the research.

3.1. Supply Chain Mapping

Supply chain mapping is a method that has been around for quite a while. Research has shown that a mapping (actually creating a picture) of a supply chain could be useful for several reasons. It helps in better understanding a firms supply chain, evaluating the current state of the supply chain and contemplating realignment of a supply chain (Gardner & Cooper, 2003). As these three points are exactly in line with the things that need clarification for the supply chain of Dreft ADW, it can be concluded that our presumption of making a mapping of the supply chain to describe the current state of the supply chain was correct. The next step in the process is then to identify what kind of mapping strategy would be most appropriate for our research.

When one is talking about mapping strategies, the distinction can be made between strategic supply chain mapping and process mapping. Gardner & Cooper made three distinctions between the two; orientation, level of detail and purpose (Gardner & Cooper, 2003), as shown in the table below

Table 3: Supply Chain Mapping vs. Process Mapping

	Supply Chain Mapping	Process Mapping
Orientation	External	Internal (typically)
Level of Detail	Low to moderate	High
Purpose	Strategic	Tactical

Process mapping is in general internally focused, directing its attention to a single process within a company. This in contrast to supply chain mapping, which often pays attention to the information and material flows through the various companies within a supply chain; from supplier to customer (Schroeder, 2000).

Selected from a broad field of literature on strategies for the mapping of a supply chain, those strategies most used in other research and/or best suiting current research will be discussed.

Value Stream Mapping

Developed by the Lean Institute, Value Stream Mapping made its entrance into the world of supply chain management in the mid-1990s (Womack & Jones, 1996). Value Stream mapping is a method to map the flow of materials and information on the level of the production floor (Rother & Shook, 2003). It consists of seven different mapping tools that can be applied to reduce wasteful activities in an inter- and intra-company context (Hines & Rich, 1997).

SCOR Model

The SCOR model is another method for mapping the supply chain. It was initially developed by the Supply Chain Council (2001) for buy-make-deliver operations of a company (Stephens, 2001). Nowadays it has been extended beyond the boundaries of a single firm into a cross industry framework for supply chain management (Stewart, 1997). Structured in four levels and based on a framework of plan, source, make, deliver and return, it mainly emphasizes the operational issues and enables companies to:

- Set business requirements and define basis for competition
- Evaluate the current performance against the required performance
- Set high-level company metrics and targets
- Set business priorities and state what needs to change

Although the SCOR model can be regarded as a process mapping approach, it possesses the abilities to make an analysis outside of single firm's borders.

Business Process Model and Notation (BPMN)

BPMN is a standard for the modeling of business processes in a Business Process Diagram (Dijkman, Hofstetter, & Koehler, 2011). It is closely linked to both activity diagrams and data flow diagrams, which are graphical representations of workflows and data-flows within a certain (information) process (Bruza & Van der Weide, 1989; Rumbaugh, Jacobson, & Booch, 2004)

These three mapping techniques have been identified as most important (or promising), because they all have certain elements that could be very useful in the mapping of the supply chain of Dreft ADW. In Chapter 5, containing the mapping of the supply chain, the choice for a certain technique will be elaborated. In this same chapter, the criteria on what technique to use will also be presented.

3.2. Collaboration in the supply chain

Collaboration in the supply chain is a concept that is found to be of vital importance in taking supply chain practices to the next level. Its emergence in its most primal forms of Vendor Managed Inventory (VMI) and Continuous Replenishment Programs (CRP) in late 1980's and early 1990s revealed the hidden potential of collaboration in the supply chain (Barratt, 2004; Ireland & Bruce, 2000; Skjoett-Larsen et al., 2003). Collaboration really took off when in the mid-1990s the concept of Collaborative Planning, Forecasting and Replenishment, a nine-step process model, was introduced (VICS 1998).

Collaboration in the supply chain is a rather broad and undefined concept and hence hard to implement, despite its clear benefits (Ireland & Bruce, 2000). When talking about collaboration it can be cited as: "*mutuality of benefit, rewards and risk sharing together with the exchange of information as the foundation of the collaboration"* (Barratt & Oliveira, 2001; Barratt, 2004; Stank, Crum, & Arango, 1999). Barrat (2004) states that this does not encompass the concept supply chain collaboration completely. He dedicates a full paper on the major elements of supply chain collaboration of which many are both enablers as well as barriers. For this full list of elements we refer to this specific paper (Barratt, 2004). We however will build on this first (rough) definition of collaboration.

Looking at this definition, there are two words/concepts that draws our attention. These concepts are *together* and *information sharing*. Collaboration only takes place when:

1. more than one actor participates and
2. when these actors share information.

It is these two concepts that will be further elaborated on. This will provide an interpretation of collaboration in the supply chain of Dreft ADW to be able to design future scenarios that can improve its performance.

With whom to cooperate?

The term 'More than one actor' naturally relates to with whom you are collaborating. There is both intercompany collaboration; working together with your direct desk neighbor or neighboring department, as well as intra-company collaboration, working together with another company. Especially this last form is of interest when talking about supply chain collaboration. Intra-company collaboration within the supply chain can on itself be divided into two separate terms: horizontal and vertical collaboration.

Horizontal collaboration refers to collaboration between companies that are in the same echelon of a supply chain; collaboration amongst manufacturers (thus Unilever, Procter & Gambler and/or Nestlé). Vertical collaboration is defined as collaboration between different echelons; collaboration between supplier, manufacturer and retailer (thus Procter & Gamble and Retailer X) (Barratt, 2004). It will be clear that in the case of this research we are focusing on vertical collaboration.

Information sharing

The second important concept was the sharing of information in a supply chain. Many articles can be found that highlight the information sharing as one of the fundamental needs for improving performance (Barratt, 2004; Lee, Padmanabhan, & Whang, 2004; Lee & Whang, 2000). Empirical evidence on the benefits of information sharing are found in more recent publications (Chen, Drezner, Ryan, & Simchi-Levi, 2000; Yu, Yan, & Edwin Cheng, 2001; Zhou & Benton Jr, 2007). Especially since the entrance of the digital age, providing the needed technology to ensure rapid sharing of huge amounts of data and the computing power to process this data, it is of vital importance to acknowledge the importance of "good" information sharing.

One of the pitfalls in the concept of information sharing is that one would focus too much on the technological aspects (Cachon & Fisher, 2000; Frohlich & Westbrook, 2001; Zhang, 2002) While enabling technology is indeed a very important aspect, one should not discard other concepts relating to the sharing of information. Implementing the technology to enable two people to share information does not automatically mean that they will (Croom et al., 2007).

Taking these two concepts of vertical collaboration and information sharing, one can start to describe the elements that need to be taken into account when defining vertical collaboration in the specific case of the supply chain of Dreft ADW. What does information sharing in vertical collaboration really mean? What are the important elements that describe "good" information sharing in the supply chain of Dreft ADW? In the next section we will examine these elements and provide an in-depth definition of these elements.

Vertical collaboration and information sharing

In this thesis the focus will be on vertical collaboration and specifically the vertical collaboration with respect to the use of information and information sharing. It is widely recognized in the scientific community and shown in business models that information sharing is at the core of a collaborative supply chain (Croom et al., 2007). Based on exploration of the broad field of literature on information sharing in vertical collaboration, this research divides vertical collaboration in the supply chain into five different element, together enabling clear information sharing. The five elements are:

1. Visibility
2. Connectivity

3. Transparency
4. Synchronization
5. Willingness

The various concepts will be discussed in more detail below as well as how they connect to the concept of vertical collaboration in the supply chain and the research project.

Visibility

The first concept that we will discuss in more detail is the concept of visibility. In defining this concept we will start with the (non-supply chain) definition of visibility. When looking at the Oxford online dictionary definitions of visibility (Unknown, 2015), the first two definitions of visibility are interesting to mention in creating an understanding on supply chain visibility:

1. The state of being able to see or be seen
2. The distance one can see as determined by light and weather conditions

Combining these two definitions, one gets a feeling for what is meant when one is talking about visibility in the supply chain; 'seeing' what happens in the supply chain. Examination of the literature providedes an unambiguous definition on the subject. Francis *et al.* (Francis, 2008) dedicated a full review paper on formulating a single, comprehensive definition on supply chain visibility.

"Supply chain visibility is the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events" (Francis, 2008)

We will use this definition of visibility, but have to make a subtle nuance to fully cover our understanding of the concept when we are designing a supply chain with increased visibility. We will define full visibility in the supply chain as:

"A state of the supply chain where everyone in the supply chain has the ability to know the identity, location … for these events (Francis, 2008).*"*

Everyone is underlined, as it puts the emphasis on who we are talking about: each company, department, person or computer in a certain supply chain, from customer to raw material supplier. In the case of full visibility it is meant *everyone*.

Ability is in italics as it places a subtle but rather important nuance in the definition. This is a situation where everyone (companies, departments etc.) in the supply chain can access data and information that is generated in other parts of the supply chain, but do not necessarily do so! Thus all actors have the *ability* to access the data and information.

Research has shown that this subtle nuance is something that is also seen in the literature. Managers across the globe indicate in various studies that it is indeed key to have or create visibility to be able to take supply chain practices to the next level. They see this as one of the main challenges that is facing supply chain managers today (Barratt & Oke, 2007; Barratt, 2004; Francis, 2008). This view however contradicts the statements of vendors of SCM software, LSP's, and transportation companies claiming to provide supply chain visibility capability (Francis, 2008).

A clear example of the impact of changes in information is the infamous bullwhip effect. It refers to the increasing variability of the demand of goods upstream in the supply chain (Chen et al., 2000; Fransoo & Wouters, 2000; Lee et al., 2004). When information flows through the supply chain it gets distorted, resulting in these inefficiencies. By increasing the visibility in the supply chain, the bullwhip effect can be diminished or even completely eliminated.

Connectivity

The second concept that is discussed, in order to better define vertical collaboration, is connectivity. In itself, connectivity is (in a non-supply chain setting) defined as:

1. The state or quality of being connected to one another

Connectivity, or being connected to one another, is of course also been described in literature. Next to the term connectivity, the concept is also often called interconnectivity or (the extent of) integration of information and delivery (Frohlich & Westbrook, 2001; Zhou & Benton Jr, 2007). We will try to combine these concepts into the one overarching concept connectivity.

In many articles, managers tend to perceive being connected to each other entails having the technological ability to share information (Cachon & Fisher, 2000; Croom et al., 2007; Frohlich & Westbrook, 2001; Zhang, 2002). This would suggest that connectivity is a purely technological issue and connectivity is driven by technological innovation and the ability of a company to attain this technology. This line of thought is contradicted by Croom *et al.* who state that connectivity is, besides a technological issue that companies have to deal with, a matter of willingness to be connected (Croom et al., 2007). This though is also endorsed by Frohlich ***et al.*** who state that interconnectivity in the supply chain can be reflected in the fact that companies with the same goals link up; there needs to be a certain willingness to create connectivity (Frohlich & Westbrook, 2001)**.** Also, more recent research showed that there is a need to include the integration of business processes, strategies and policies (Pieter van Donk, Mortensen, & Lemoine, 2008; van Hoek, Lenny Koh, Saad, & Arunachalam, 2006; Wei, Liang, & Wang, 2007). These articles show that it is vital to recognize the sociological side of connectivity.

As we are dealing with the concept of willingness in a separate section, we will define connectivity as:

"The ability of companies to be connected to each other through both technological and sociological solutions (Croom et al., 2007; Frohlich & Westbrook, 2001).*"*

Again, we highlight the word ability, because we want to place the concept in a design perspective, as the goal of this literature research is to provide a basis for future supply chain design choices with respect to vertical collaboration. Full connectivity would mean that two companies have both the technological solutions as well as the managerial conviction to share information throughout the chain.

To better explain what connectivity entails, we will provide a few examples. Connectivity from a technological viewpoint would mean that there is an extensive IT infrastructure within the companies of a supply chain (retailer-manufacturer-supplier) to be able to share the needed information. High connectivity would in this case mean that information on orders, sales or anything else can be updated every minute (or second).

The sociological aspect of connectivity can be explained with an example on order and replenishment processing. Managers could increase connectivity by sitting together and align order and replenishment processes, of the various steps in the supply chain, to optimize the overall efficiency. No specific new technological investments need to be made, but managers do need to coordinate these kinds of meet-ups or else these will remain absent. This can be seen as the sociological aspect of connectivity.

Transparency

The third concept of vertical collaboration in the supply chain is transparency. Just as for the earlier discussed concepts, we will first provide the definition of an online dictionary:

1. Allowing light to pass through so that objects behind can be distinctly seen
2. Easy to perceive or detect

This provides us a first insight on what to feel when we are talking about transparency. Just as for the other concepts, we first performed a literature review before defining the concept of transparency. A broad search on organizational transparency yielded the following definition by (Schnackenberg & Tomlinson, 2014)*:*

"The perceived quality of intentionally shared information from a sender (Schnackenberg & Tomlinson, 2014)*."*

At first glance, in this way transparency resembles the definition of visibility. However there is a subtle difference that distinguishes the former from the latter. The subtle, but very important, difference between transparency and visibility is that transparency here implies the visibility in contexts related to behavior of actors in the supply chain (i.e. proactively engaging and communication with the key stakeholders in the supply chain choices (Crum, Poist, Carter, & Liane Easton, 2011)).

Table 4: The metaphor of transparency (Lamming et al., 2001)

THE METAPHOR OF TRANSPARENCY: THE BEHAVIOR OF LIGHT AS THE ANALOGY FOR THE TRANSFER OF INFORMATION OR KNOWLEDGE IN RELATIONSHIPS

	Opaque	Translucent	Transparent
Geological case (light shining through mineral)	Light cannot even penetrate the surface of the substance.	Light can enter and exit the surface of the substance, but with distortion.	Light enters and exits the surface relatively undisturbed.
Business case (information shared between two organizations)	For any of a variety of reasons, no information is shared between the parties; even operational day-to-day information is obscured.	Outline information only is shared — interface conditions or partial data. This can be similar to "black box" collaborative design. If used tactically, it may be akin to cheating.	Information is shared on a selective and justified basis. Development of information leads to shared knowledge and collaborative abilities.

If one performs a literature search on transparency in the field of supply chain management, it is quickly discovered that there is only a very limited number of publications that discuss transparency as a separate concept or mention the term. One of the few exceptions is Lamming *et al.,* who have as one of the few in this field, dedicated time to defining transparency. As we have done above, they made an analogy between the geological case and business case on the definition of transparency (Lamming, Caldwell, Harrison, & Phillips, 2001).

They stated that in a transparent supply chain, information is shared on a selective and justified basis. The analogy that can be made with geology is light shining through a mineral, in a transparent mineral the light enters en exits the surface undisturbed (Lamming et al., 2001). The analogies for different extents of transparency are given Table 4.

Before a definition of transparency in the supply chain is formulated, based on the findings in literature, it is useful to look back at the definition of visibility. The nuance within the concept of visibility, namely that people might have the needed information but not necessarily use it, forms the needed last piece of the puzzle clearly define transparency in a supply chain context. Combining all different insights on the concept of transparency the following definition surfaces:

"The extent to which intentionally shared information is being used throughout the supply chain; the penetration of information ***[bron]****."*

The word extent is emphasized, because one talks about a complete supply chain. If for example sales data is available for everyone in the supply chain (retailer, manufacturer, supplier), but is only used by the retailer and manufacturer, the supply chain is not completely transparent. In the analogy with geology, the supply chain is a mineral that is 2/3rd transparent.

The term intentionally is emphasized, because this relates back to visibility. For example, if an actor in the chain decides to change the information, the chain's full transparency will ensure that the receiver of information knows why and how the information is changed (changing sales-data into a forecast).

Synchronization

The fourth concept that helps define the elements of vertical collaboration in the supply chain is synchronization. A dictionary definition of synchronization or synchronize gives:

1. To cause to indicate the same time, as one timepiece with another

Synchronization can be seen as the coordination of events so as to have systems operate in unison. The famous saying *"lets synchronize our watches"* clearly explains what is meant by synchronization. Two people coordinate events (the setting of their watches) to have their systems (the watches themselves) operate in unison.

Synchronization in a supply chain context is defined by Holweg et. al. (2005) in the following way.

> *"Synchronized supply eliminates one decision point and merges the replenishment decision with the production and materials planning of the supplier* (Holweg, Disney, Holmström, & Småros, 2005)*."*

Contrary to the previous three concepts, synchronization is not something that is required to have efficient information sharing (unlike visibility, transparency and connectivity), but it is a matter of how to use shared information. This definition shows that synchronization in a supply chain setting is a guideline for which information should be shared by the various actors in a chain to make information sharing effective. A classic example is the "double marginalization", where the retailer does not consider the suppliers interests when setting his order quantity (Spengler, 1950). Or the other way around, where the supplier does not match his production with the demand from the retailer (Sahin & Robinson, 2002).

In literature, synchronization is often are often (wrongly) used interchangeably. Where coordination addresses the company's strategic choices in supply chain design, synchronization is more about choices on how to align the supply chain on an operational level (Holweg et al., 2005; Simatupang, Wright, & Sridharan, 2002; Xu & Beamon, 2006; Xue, Li, Shen, & Wang, 2005).

By synchronizing the supply chain, various different benefits can be gained. Research has shown that key drivers of logistics synchronization are the need for reducing the uncertainty, variability and lead times of a supply chain, thereby dramatically reducing inventory costs (up to 50% inventory reduction) and increasing customer service levels (Disney & Towill, 2003; Simatupang et al., 2002; Waller, Johnson, & Davis, 1999).

Willingness

The last concept that we will shortly touch upon here is the concept of willingness. Although willingness is a concept that everyone can relate to, for the sake of consistency the definition of willingness in a non-supply chain setting is given:

1. Ready, eager, or prepared to do something

When talking about visibility, transparency connectivity and synchronization throughout the supply chain, it often gets overlooked that all players must be willing to collaborate. In fact, willingness is incredibly important when collaborating in the supply chain (Croom et al., 2007; Crum et al., 2011). Key players in the supply chain make choices what and (more importantly) what not to share with others. Although various research has shown that collaboration in the supply chain would lead to shared profits, the willingness to actually work together leaves much to be desired in the real-world.

3.3. Value of information

In the previous sections, the different elements of vertical collaboration and information sharing are discussed. This is however not the first research that has been conducted on the effects of information sharing. Over the years various other researchers around the world have tried to quantify the effects of information sharing in a supply chain (Cachon & Fisher, 2000; Gavirneni, Kapuscinski, & Tayur, 1999; Lee, So, & Tang, 2000). In short we will highlight these three relevant papers that have tried to quantify the effects of information sharing in the supply chain.

Although not many papers give actual tangible results on the value of information, Cachon & Fisher (2000) have written a paper in which they did provide actual cost saving percentages (Cachon & Fisher, 2000). In a numerical study they found that full information sharing, compared to no information sharing, could lower supply chain costs by 2.2% on average and 12.1% at the maximum. Next to that they performed a numerical study on reducing lead-times and batch size. Reducing lead times by almost 50% would reduce costs by 21% on average, cutting batch size in half would reduce costs by 22% on average. They conclude that information technology could therefore better be used to smoothen the material flow than to expand the information flow.

Lee, So & Tang (2000) set out to quantify the benefits of demand information sharing between retailers and upstream suppliers (Lee et al., 2000). They performed this research from a manufacturer point of view, because they believe that the manufacturer has most to benefit from information sharing (much like the current research). Although they do not quantify the effect in absolute percentages (like Cachon & Fisher (2000)), they do provide valuable insights on overall trends. Their simulation study aims at investigation the value of sharing information in a highly volatile environment. When information is shared, the relative inventory reduction at the manufacturer increases with increasing volatility and with this come larger cost benefits.

Gavirneni, Kapuscinski and Tayur (1999) performed a research in which they set out to estimate the savings at the supplier with information sharing and when this is most beneficial (Gavirneni et al., 1999). They looked into the relationships between manufacturing capacity, inventory and information at the supplier level, as well as the influence of demand distribution and inventory policy (minimum order quantities) of the retailer on these concepts. Amongst other, relevant conclusions that can be drawn from this paper are: 1. savings increase with increased capacity (larger production quantities), 2. information is most beneficial at moderate values of end-item demand variance and 3. information is less beneficial for large minimum order quantities of the retailer.

3.4. Literature Research Overview

This chapter has provided the reader an overview of the relevant literature for this research. An in depth study on collaboration in the supply chain provided the framework with which it is possible to define good information sharing in vertical collaboration. Five concepts were observed as enablers for information sharing in vertical collaboration. Next to that, three papers were highlighted that have tried to quantify the value of information in the supply chain. Also an overview of different supply chain mapping techniques was presented. In the next chapter an analysis will be done on the current state of the supply chain of Dreft ADW.

4. Current State Supply Chain Analysis

Since 2007, the new range of Dreft Automatic Dishwashing (Dreft ADW) tablets has been on the market. These revolutionary tabs were the first and only ones to have both powder and liquid materials (FoodMagazine, 2008). With a total market share of 24% in 2015, it is the second largest automatic dishwashing detergent in the Netherlands (Riezebos, 2014). In this case-study we are looking at the specific customer of Procter & Gamble, namely Retailer X.

Dreft ADW is a collective term for different types of Dreft ADW patches. There are all sorts of different flavors, chemical compositions, bag sizes, colors etcetera. Each different bag of Dreft is called a Stock Keeping Unit (SKU). Of all these SKUs only a limited amount is sold in the stores of Retailer X. In the FY14/15, Retailer X had 15 SKUs in store, Figure 5 shows these SKUs.

Figure 5: Overview of in-scope Dreft ADW SKUs

An analysis of the sales of last year has given a few remarkable but very important insights in the market of Dreft ADW.

In this chapter, the current state of the supply chain will be discussed on the basis of the predefined KPIs Service, Inventory and Costs. First an overview of the definition of these KPIs is given and subsequently the actual state of the KPIs, according to a thorough data analysis, is presented.

4.1. Key Performance Indicators of the Current Supply Chain

In this chapter, an overview of the analysis steps of the current state of the supply chain is given., The goal of the analysis is to identify the current status of the performance of the supply chain. Although a quick glance at the literature shows that a lot is written on how to assess the performance of the supply chain, such an undertaking remains outside of the scope of this research. At the start of the project, the initial assignment from Procter & Gamble stated that one of the deliverables should be improvements in terms of *their* KPIs. Therefore we have chosen to use the three KPIs that are used by Procter & Gamble to assess the supply chain. These three KPI's were:

1. Service
2. Inventory
3. Costs

To assess these KPIs, it is important to be able to quantify these three concepts. Procter & Gamble has a standard way of quantifying these KPIs which will be discussed next.

Service

At Procter & Gamble this KPI is identified as Service As Measured By the Customer (SAMBC). This has two implications; not only is service measured differently for each customer, moreover the desired level of service can differ. Because in this example one looks specifically at the customer Retailer X, service is measured in the following way:

$$SAMBC\,\% = 1 - \frac{\sum missed\ cases}{\sum cases\ ordered}$$

This formula needs a little more explanation:

- Because Procter & Gamble is Vendor Managed Inventory (VMI) partner of Retailer X, it is Procter & Gamble who is responsible for the inventory levels of Procter & Gamble products in the distribution center of Retailer X. Therefore In this formula, *missed cases* is the amount of cases of product (Dreft) that are not in the Distribution Center (DC) of Retailer X when they want to push the product through to the stores. Retailer X has multiple DCs, however Dreft ADW is stored in only one, in the DC in X.
- *Total cases ordered* are not actual orders, but it is the amount of cases of product that Retailer X wants to ship from their DC to the stores.

The ratio (expressed in percentage) between the *missed cases* and *total cases ordered* is the SAMBC for Retailer X. The desired service level is (determined together with Retailer X) set on ***X%***. This means that if Retailer X wants to send a 1000 cases to the stores on a certain day, 984 should be at least available in the DC of Retailer X. SAMBC is a cumulative measure, which is measured throughout the year.

Important to mention here is that, because the problem owner of the project is Procter & Gamble, the official measure of service will be the SAMBC as defined above. However, Retailer X has their own service measure. Retailer X defines the service level in respect to *their* customer, the end-consumer like you and me. In that case the service level is defined as the *on-shelf-availability,* the percentage of time that there is at least 1 product available for consumers on the shelves. Although not the official measure, the on-shelf-availability will be discussed in the data analysis.

Inventory

Inventory is a concept that is relatively easy to quantify. It is the amount of product that is currently stored somewhere in the chain. In the supply chain of Dreft, the product is stocked at several points in the supply chain. More information on these points and amounts of product will be given later on in this chapter.

However, to be able to assess the KPI Inventory and actually qualify the value that follows from a data analysis, the measure Inventory is not the absolute number of cases but rather the so-called total Days-On-Hand (DOH). This DOH can be calculated as follows:

$$Days\ on\ Hand = \frac{Total\ Chain\ Inventory}{Sales\ per\ Day}$$

Just as the KPI SAMBC, this measure needs some more explanation.

- When calculating DOH, normally the forecast of the total sales for the coming period is used. However in the data analysis done for this project, the DOH at each data point were calculated from the inventory level at that time and the result of the actual sales following from that date. In this way, the *actual* DOH at that point in time are calculated (in hindsight).
- Total Chain Inventory and Sales are both measured in cases of Dreft ADW products, resulting DOH to be measured in Days.

On its own, DOH does not say anything about the quality of the KPI. For example, is a current inventory level of 20 Days on Hand good or bad? Does there need to be less or maybe more inventory? To be able to quantify the value of the KPI Inventory, it needs to be compared to the total time it takes for the product of topic (in this case Dreft ADW) to travel from manufacturing to the consumer. Later on in this chapter the lead times in the chain will be evaluated and together with the data analysis on the inventory, an indication can be made on the current state of this KPI.

Costs

The third and last KPI is the cost of the supply chain. This is easily quantified; the KPI is defined as the total cost of the product to the customer from the moment it leaves the production line. This includes all handlings or “touches” that the product undergoes. The KPI cost is measured in Euros, but just as for the KPI inventory, no real conclusions can be drawn from a data analysis on the current absolute values as they cannot be placed in any context.

The costs within the supply chain are often a sensitive subject, especially when looking at the total supply chain where different actors have to be taken into account. As the project owner (and in this case the problem owner) is Procter & Gamble, data about the costs of their part of the supply chain is available. Retailer X, however, is not willing to share their cost data and will therefore have to be left out of the analysis.

4.2. Mapping of the current supply chain

In order to assess the current state of the supply chain KPI’s a complete mapping of all processes, actors, and interactions between these actors on a top level has been made. In the literature overview, three possible options were for mapping techniques were presented: Value Stream Mapping, SCOR model and Business Process Model & Notation. In making the trade-off which technique to use, we need to evaluate what it is that we actually want to map.

The main research objective is to identify what the impact is of vertical collaboration on the supply chain KPIs. This provides us with two outputs that the mapping of the supply chain should give us:

1. It should provide information on the KPIs
2. It should provide information on the processes affected by vertical collaboration

The mapping technique should therefore discuss the supply chain across the boundaries of the supply chain companies, provide insights in the flow of information and flow of materials and obtain enough detail to assess the supply chain KPIs.

Within these boundaries it was chosen to use a hybrid form of both Value Stream Mapping and Business Process Model & Notation as the techniques to map the supply chain with. On the one hand, Value Stream Mapping would provide us with the insights needed to assess the supply chain KPIs, BPMN on the other hand would help identify the flow of information. It must be said that Value Stream Mapping was not done on the production floor level detail, as is usually done. It would have taken too much time to completely walk through the supply chain and would not add that much value to the research. With a more top level mapping the needed information could also be extracted. However, BPMN was done on a less detailed level. As in this case-study one looks at collaboration across companies, the detailed process mapping for all these departments on their own is less relevant for the research. In this section the mapping will be discussed on a top level. A more in-depth actor analysis is given in chapter 5 and the complete flowchart of the supply chain is given in Figure 6 on the next page.

As stated earlier, when mapping a supply chain there are often two different streams. First, there is the flow of materials, in this case Dreft ADW products, that describes all the processes and stages the tangible product flows through from the (raw material) supplier until the consumer who uses the Dreft patches in their dishwashing machine.

The other stream is the flow of information. This is the intangible information that the different actors give to each other to help keep the flow of products going. This is for example the orders that are placed by the retailer, the sales forecasts made by commerce departments of various actors. This flow of information and the flow of materials will (shortly) be discussed below.

4.3. Material flow

The flow of materials is a relatively straightforward linear process of the transformation of raw materials into a patch with Dreft that ultimately gets transported to the end consumer.

First the, raw material supplier retrieves the natural resources and processes these into the chemicals that form the raw materials for the manufacturer of Dreft ADW (Procter & Gamble). These raw materials are then made ready for transport and subsequently transported by a third party logistics company to the production plant of Procter & Gamble in Mechelen, Belgium.

At the production site, the raw materials are unloaded and stocked until they are ready to be used in the production process. During the production process, the raw materials are being transformed into batches of Dreft ADW patches, packed in Dreft bags, placed in cases, put onto pallets and loaded into a truck that immediately shuttles the products after a production batch to the Procter & Gamble distribution center in Rumst, Belgium.

At the Procter & Gamble DC, the truck gets un-loaded, the full pallets are stored in the DC until they are ready to be transported to the retailer. The DC works with the FIFO (First In First Out) principle meaning that a pallet that arrives first will leave earlier than a pallet arrived later. When ordered by the retailer, the pallets are picked and loaded for transport to the retailer. A third party logistics company will then transport the products to the respective retailer that ordered the product. In our case this retailer is Retailer X. The third party logistics company will thus transport the product to a distribution center of Retailer X (RETAILER X DC). In the case of Dreft ADW, this DC is the national DC of Retailer X and is located in X, the Netherlands.

When the truck arrives at the national RETAILER X DC, the truck gets un-loaded and the pallets are placed in the warehouse. Also Retailer X executes a FIFO strategy and when the products need to be transported to the store, the cases of Dreft are picked and loaded on the truck of a third party logistics company to be transported to the store.

As soon as the truck arrives at the store, the products get un-loaded and the bags of Dreft are placed on the shelves in the store. All products that cannot immediately be placed on the shelves get stored in the stockroom of the respective stores. The whole process ends when a consumer buys the bag of Dreft ADW, takes it home and uses it in their dishwasher.

Specific timings, volumes and other important details of the material flow are discussed later on in this chapter, but in the figure below a schematic overview of the material flow is given. The next section will discuss the stream of information, which flows in the opposite direction of the flow of materials and is a rather complex multi-actor system.

4.4. Information Flow

replenishment is known, this is communicated to the Transport Operations Department of Procter & Gamble and the Supply Planning department of Procter & Gamble.

Vendor Managed Inventory

> *Procter & Gamble is a Vendor Managed Inventory partner of Retailer X, meaning that Procter & Gamble is responsible for maintaining the right inventory levels at the DC of Retailer X. In this case, the "right inventory levels" mean that the total inventory is always below 7 Days on Hand. This number is imposed by Retailer X as a condition for entering in VMI collaboration. Although the stock levels are controlled by Procter & Gamble, Retailer X is the owner of the inventory; the products present at the DC of Retailer X are sold by Procter & Gamble to Retailer X.*

The Transport Operations department ensures that the product replenishment of the Retailer X DC actually occurs. This department contacts a third party logistics company that transports the products from the DC of Procter & Gamble to the Retailer X DC.

The Supply Planning department of Procter & Gamble is responsible for maintaining the right inventory levels at the Procter & Gamble DC (in Rumst). They combine the product demand of the various retailers that are being supply by the Procter & Gamble DC and the actual stock levels at the warehouse into one total supply demand for the DC. This supply demand is the primary input for the Demand Forecast department.

The Demand Forecast department of Procter & Gamble has two information inputs: long-term (promotional) forecasts from the commerce department of Procter & Gamble and the supply demand from the Supply Planning department. The department looks at the (more) long term demand for products. The long-term forecasts are not restricted to one retailer, but the aggregated forecast for all promotions of all retailers of a specific Selling Market Organization (SMO) on the long-term. The Demand Forecast department generates a total Product demand for their SMO. In the case of Dreft ADW and Retailer X, the SMO is FBNL (France, Belgium, Netherlands, Luxembourg).

This product demand is then communicated to the Demand Requirements Planning department. Moreover, the inventory levels at the DC of Procter & Gamble are retrieved from the warehouse. These two information inputs combined, generate the amount of products that is needed for the replenishment of the Procter & Gamble DC. As this amount is the amount that needs to be produced by the plant, the replenishment is the Production Demand Forecast (PDF), which is communicated daily to the production plant.

The PDF of each SMO (the PDFs of all Demand Requirements Planning departments of the various SMOs) is collected by the Production Supply Planning department of Procter & Gamble. Next to that, the department receives the inventory levels of the various Procter & Gamble DCs for which the plant produces. These two information inputs are combined and generate a production order, which is used by the Production Planning department to make a production planning. This planning is then executed in the plant and the Dreft ADW patches are produced. The production planning also automatically triggers a third company logistics company to shuttle the patches to the Procter & Gamble DC.

This ends the cycle and the material flow and information flow get combined again. It needs to be mentioned here that on a managerial level, the "flow of information" is that Retailer X and Procter & Gamble have the same intention of selling as much as possible Dreft ADW. This intention is shared by all the different departments, as confirmed in various interviews with the people responsible. The general assumption will thus be made that each department will do its upmost best to deliver upon the needs of the supply chain.

Retailer X and Procter & Gamble have agreed on the possibility of a daily replenishment cycle, thus the flow of information is started daily. It depends on the inventory levels and other information input throughout the complete chain whether the POS data eventually triggers production of Dreft ADW. In the next section the current state of the supply chain according to the data of the past fiscal year (FY14/15) will be evaluated in reference to the earlier discussed KPIs.

4.5. Current State Data Analysis and KPI evaluation

In this section the current state of the supply chain will be evaluation on the basis of the earlier defined KPIs: Service (SAMBC), Inventory (DOH) and Costs. The data of the past fiscal year is used as input for this evaluation and the outcome of the data analysis is to identify the problems and shortcomings of the current supply chain, possible short-term and long-term solutions that would arise with implementing the principles of vertical collaboration (visibility, transparency, interconnectivity and willingness). In this section only the relevant data that ostensibly seems to influence the different KPIs is presented.

Service

The first KPI that will be discussed is the KPI service, or as the SNO department of Procter & Gamble calls it: Service As Measured By the Customer. Next to that the “unofficial” measure on-shelf-availability, as this measure provides another perspective on the desired SAMBC level. As explained earlier in this chapter, SAMBC is measured as the missed cases relative to the ordered cases and OSA is the percentage of time the respective product is available for the consumer to buy. The SAMBC is measured as:

$$SAMBC = 1 - \frac{Missed\ cases}{Total\ cases\ ordered}\ \%$$

Therefore the analysis was done on both the missed cases and total cases ordered in FY 14/15.

Missed cases

A first clarification needs to be made about the definition of missed cases. The concept missed cases is defined by Procter & Gamble as the amount of cases that cannot be delivered at the point that they are ordered. This does not mean that they are not delivered at all; they are backordered and delivered on a later point in time.

Data analysis showed that over the FY 14/15, the total amount of missed cases of Dreft ADW was **X cases,** which roughly translates to X bags of Dreft ADW. This is the total amount of missed cases over all different SKUs (all 15 SKUs) that have been sold over the past year by Retailer X (remember that we are looking at the missed cases in the last part of the supply chain; RETAILER X DC to Store).

The Order Management department analyses the root-causes of the missed cases of all products and keeps a track record. An analysis of the root-causes of the misses in Dreft ADW is shown in Figure 7. The Order Management department identified 5 main root-cause categories that are able to incorporate all causes of missed cases:

- Customer: the customer (Retailer X) has made a mistake in their processes causing the missed cases (for example not being able to unload the truck with products).
- Forecasting: the forecast of a promotion was not correct, causing a shortage in the Retailer X DC.
- Supply: there was a fault in the processes of the supply of products (for example a miscommunication in the loading of a truck, causing them to be delayed).
- OM (Operations Management): a human error by the Operations Management department in for example releasing the order.

- OTHER: other causes that cannot be placed under one of the above and are not recurring problems.

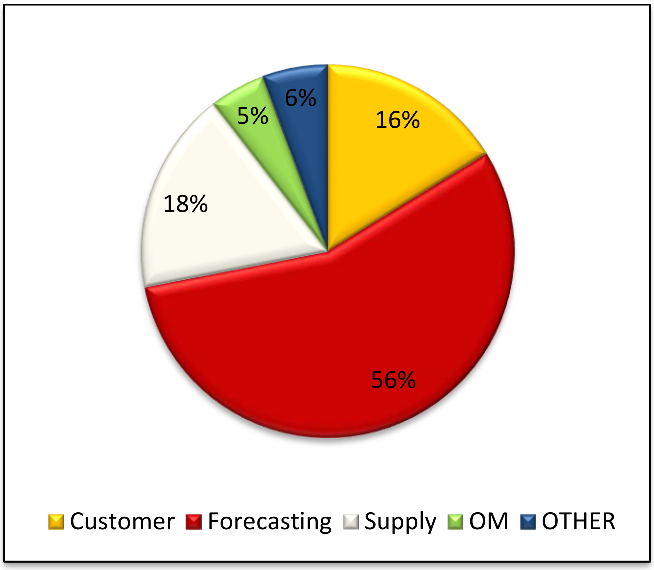

Figure 7: Pareto analysis on service level root-causes

A quick look at the root-cause analysis shows that 56% of all missed cases (X cases) can be root-caused as a forecasting problem. A forecast being too low (resulting in a too low stock) has dramatic effect on the amount of missed cases.

To sum up, the key take-out of this analysis: is there a possibility to either increase the forecast accuracy, or is there a possibility to make the supply chain less dependent of forecasts?

Total cases ordered

The second important parameter of SAMBC is the total cases ordered. This is the total amount of cases in the FY14/15 that were "ordered" by the Store Replenishment department of Retailer X at the Retailer X DC to be shipped to the stores of Retailer X.

The total amount of cases shipped from the Retailer X DC to the stores of Retailer X is **X cases**. Of this volume, more than 70% is shipped as a result of a promotion week. This is an interesting insight, especially when looking at the root-causes of the missed cases.

Service As Measured By the Customer

The data points acquired in the previous sections can be used to calculate the SAMBC of Dreft ADW. In the table below, the SAMBC per SKU is given. The main conclusion that can be drawn from this table is the fact that the SAMBC level, ***X%***, of Dreft ADW at Retailer X is way below the set target level of X%. The main problems occur in promotion weeks, where much larger shipments need to be met, causing the supply chain to be heavily dependent on the forecast accuracy. It must be noted here that there are no large variations the kind of promotion, all promotions are either 1+1 or 2+1. In any case, all promotions cause a strain on the supply chain. In short one can conclude that the misses induced by forecasting errors alone are enough to not be able to meet the required service level.

If one looks at the service levels of the promotional weeks and the weeks without promotions, a big gap can be identified. The SAMBC level in regular weeks is X%, meeting the requirements exactly. However, in promotional weeks the service level is a dramatic X%. Because Dreft ADW is promotion driven, meaning (much) higher sales numbers in the promotion weeks, the low service level in these weeks have an even larger impact on the total SAMBC.

On-Shelf-Availability (OSA)

As explained earlier in this chapter, the on-shelf-availability is the measure of the percentage of time that at least one product is available on the shelf for the consumer to buy. The OSA level of all Dreft ADW products is X%, meaning that although the SAMBC is not on the required level, the OSA is. Even more interesting is the fact that often the misses in OSA (thus times where no product is on the shelf) are not directly related to missed cases; the data shows that weeks with low SAMBC levels do not automatically result in a low OSA level.

Sub-conclusion on Service

There are three main conclusions that can be drawn from the KPI service:

1. The service level (SAMBC) is X% below the target level of X%.
2. Misses are more than 50% of the time due to forecasting problems and the misses in these promotional weeks are the main cause of the low SAMBC level.
3. The OSA is on target at X%, meaning that a miss in SAMBC does not directly influence the OSA. Moreover, the data does not show a link between large SAMBC misses and OSA misses.

One could argue that when companies collaborate in the supply chain, one single service measure should be used throughout the chain. Especially since the common goal of both companies is too sell as much Dreft ADW as possible, it might be useful to design the supply chain in such a way that the OSA gets close to 100% instead of focusing on the right SAMBC.

The SAMBC leaves much to be desired, but how does it influence the other KPIs? One might expect that the inventory levels at Procter & Gamble DC might be too low in order to meet the demand of Retailer X (especially during promotional weeks).

Inventory

The inventory is measured in Days on Hand (DOH), the amount of days that the inventory can supply the stores. Of course in different stages of the material flow products are stocked and by analyzing the different inventory points of the supply chain (store, RETAILER X DC, Procter & Gamble DC), the total DOH of the supply chain can be measured. A quick recap, the formula to calculate the Days on Hand is:

$$Days\ on\ Hand = \frac{Total\ Chain\ Inventory}{Sales\ per\ Day}$$

This section will present the results of the data analysis on the total chain inventory at each stage of the material flow where finished products are stored. Also, a quick overview of the Sales per Day will be presented.

Sales per Day

As mentioned in the introduction, the amount of Dreft ADW that is sold in Retailer X stores, is approximately 0.75 million bags a year, with ± X% sold on deal (in promotional weeks). When looking more closely at the buying behavior of the consumer, the regular sales are very steady throughout the year. Figure 8 shows the sales throughout the year, on a weekly basis. There are 10

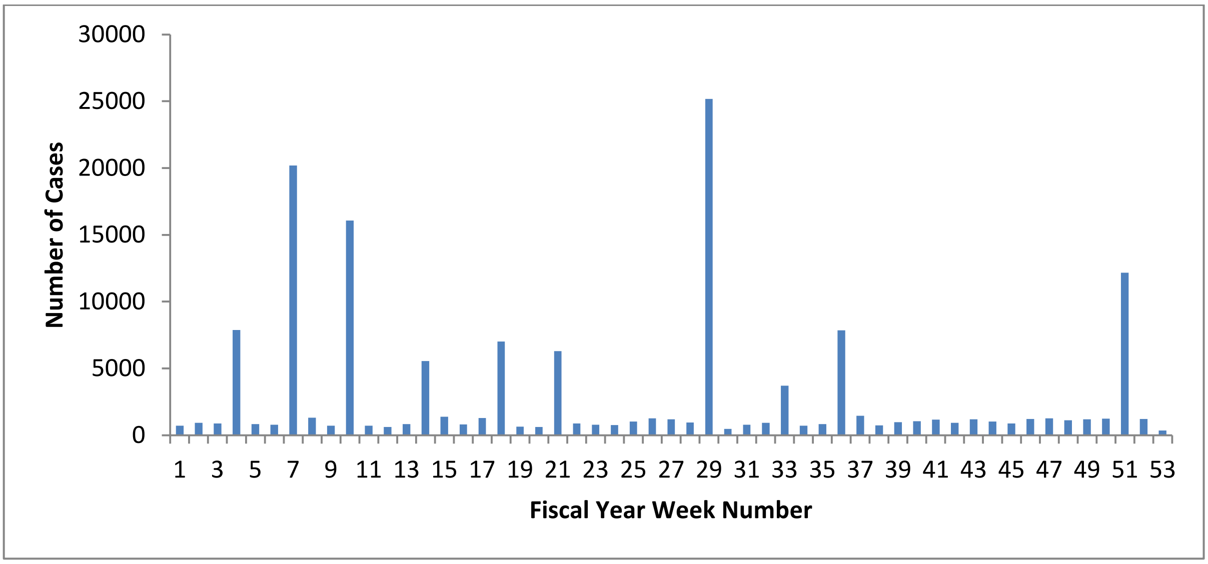

Figure 8: Dreft ADW sales at Retailer X stores

weeks where there was a promotion (showing the huge increase in sales). The rest of the weeks the sales are steady, not really influenced by the time of year. One could argue that the regular sales drop after a promotion, but that cannot be conclusively said for each promotion. Therefore, one can conclude that average daily sales fluctuate between around 120 to 160 cases.

Inventory at the Retailer X Stores

The first step in identifying the total DOH of the supply chain, is calculating the average DOH of the stores. Thus, how long can the stores actually supply the consumer if they do not get replenished?

Because the inventory level was taken in a regular week, the promotion weeks in FY 14/15 result in downward peaks. Furthermore, there are some outliers in the beginning of FY 14/15 as a result of low sales in these weeks. Taking this into account, the average DOH throughout the year can be said to be approximately X days (X weeks).

Inventory at the Retailer X DC

The next point of product storage, when walking up stream in the material flow, is the Distribution Center of Retailer X. The same calculation is done for the inventory at the Retailer X DC as for the Retailer X stores to calculate the DOH. The aggregated inventory of all SKUs in the DC over FY 14/15 is divided by the actual sales throughout the year. Contrary to the calculations done on the inventory levels of the store, the actual inventory levels throughout FY 14/15 at the Retailer X DC were available and were thus used in the calculations.

Figure 10: Weekly days on hand at the Retailer X DC

The VMI partnership agreement between Retailer X and Procter & Gamble stated that on average the DOH in the Retailer X DC should be below X days. The graph displays that Procter & Gamble approaches this value, but do not meet the requirements. The data shows that the average DOH in the FY 14/15 was X weeks, thus X days.

Inventory at the Procter & Gamble DC

One step up the material flow is the Procter & Gamble DC. This is the last point in the supply chain where finished Dreft ADW products are stored and calls for a slightly different kind of analysis. As explained in the material flow, the products stored in the Procter & Gamble DC are not designated for one specific customer. This means that when calculating the DOH in the Procter & Gamble DC, one needs to take into account that Dreft ADW is not only being shipped to Retailer X, but also to other retailers.

When calculating the Days On Hand in the Procter & Gamble DC, it is assumed that Retailer X holds a “virtual” stock. Although no designated Retailer X stock exists, in calculating the DOH in the supply chain of Dreft ADW for Retailer X the assumption is made that there is one. Figure 11 shows the DOH of the Procter & Gamble DC.

Figure 11: Weekly days on hand at the Procter & Gamble DC

The graph shows a relative constant Days On Hand, with an average over FY 14/15 of X days (X weeks). Important to notice in is that the Days On Hand in the Procter & Gamble DC never dropped below X week, indicating that there was always stock available. So the question arises: why is the SAMBC below the targeted value if there was always stock available?

Total Days on Hand

Now that a complete analysis is done on the DOH of the various storage points of Dreft ADW in the supply chain a number can be given on the DOH of the complete supply chain. By simply adding up the different DOH values, we come to a total supply chain DOH:

X Days roughly translates to X months of inventory, meaning the bag of Dreft ADW bought by the consumer is, on average, more than X months old (according to the FIFO practices of all the actors in the supply chain). Now that one knows this number, is this good or bad? Is there a lot of inventory in the chain? To be able to evaluate this number, an analysis on the lead-times is necessary

Lead Time

Earlier in this chapter KPI Inventory was discussed. It was determined that the KPI should be measured in Days On Hand. However, the total DOH (on its own) cannot be used to assess the quality of the supply chain. For example, if it takes the boxes 2 months of "travel time" to reach the store shelves, 2 months of inventory can be regarded as low. Therefore an analysis needs to be done on the lead-time of the different processes in the Material flow. Figure 12 shows the material flow and the lead-times of getting

Figure 12: Dreft ADW supply chain representation and lead-times

It can be seen that the total lead-time of the supply chain varies between X and X days. This includes production time and all other processes in the material flow (as shown in chapter 4, Figure 6). It is thus possible to rather quickly react to changes in the sales.

Sub-conclusion on Inventory

The total chain inventory, measured in Days on Hand, is X days. When this is compared to the total lead time of the chain, a minimum of X days, there is an enormous amount of stock in the supply chain. Most of this stock is situated in the stores and the distribution center of Procter & Gamble; the inventory levels at the DC of Retailer X come closer to this lead-time.

This raises two questions:

- Why is there so much stock of Dreft ADW in the complete supply chain to Retailer X?
- How come that the SAMBC level is not sufficient with so much stock available?

Before we try to answer these questions, we will first discuss the total supply chain costs.

4.6. Costs

All processes needed to get the product to the consumers cost money. Because Retailer X was not willing to share the data on their supply chain costs, it would only be possible to assess the different cost buckets of Procter & Gamble. For this reason, it was chosen to leave the different costs within the supply chain outside the scope of this project. However, to give the reader a feeling about how the different costs are divided, the overview below displays how the total financial burden can be assigned to different cost buckets.

Sub-conclusion on Costs

It would have been nice to include the costs of the other actors in the material flow, to see whether or not cost reduction steps can be made and where in the chain this can be done. However, because information on profit margins of Procter & Gamble, nor general cost information of Retailer X is available, this cannot be done. The only costs that will be incorporated in the remainder of this research are the costs of inventory storage at the Procter & Gamble DC.

4.7. Problems & Shortcomings of the Current Supply Chain

Now that the current state of the supply chain of Dreft ADW has been analyzed, it is possible to identify the problems and shortcomings and subsequently try to come up with short and long-term solutions, by implementing collaboration strategies.

Service

The focal point of Procter & Gamble is to be the number 1 supplier in the Fast Moving Consumer Goods (FMCG) market; this is directly related to the service that they can offer their customers. It is therefore even more striking that especially service is way below the target levels that are desired by these customers. When analyzing the root-causes behind the service levels, it could be seen that 56% of all problems are caused by a wrong forecast. This root-cause alone is enough to bring the SAMBC below the desired X%. On the bright side, when developing a solution for the forecast inaccuracy or a way to decrease the dependency on the forecast accuracy, the service problem can be solved.

Zooming in on the misses caused by a wrong forecast, one can see that a faulty forecast for only one promotion can cause a large amount of misses. Seemingly, it can thus be concluded that misses were caused because of the limited inventory. However, this is too short-sighted, as the data analysis of the inventory in the supply chain showed that at least Procter & Gamble was never out of stock in their distribution center. So what is going on here? How come that, although there is enough stock, there are still missed cases?

Interviews with stakeholders reveal that the issue is not per se too little stock being available, but the lack of alignment between the ordering processes and flow of information during promotional. This is further explored in Chapter 5, the Stakeholder Analysis, but in short what happens during a promotion week is the following:

- Before the promotion, a forecast of the sales is communicated between Retailer X and Procter & Gamble. At this point, all the promotional processes are set in place (explained in the chapter stakeholder analysis).
- The Monday of a promotion week (the first day) is used to determine the final forecast for the rest of the week and at the end of Monday this forecast is fixed. It is at this point that the problems arise.
- Retailer X uses the new forecast to replenish the stores. However, this new forecast is only shared on Tuesday morning with Procter & Gamble. This causes the replenishment of the Retailer X DC to occur *after* the picking for replenishment occurs.

This does not have to be a problem, because this is exactly what safety-stocks are for. However, because the sales are so much higher during promotion weeks an (in percentage small) uplift can cause large misses. Next to that, promotion sales are highly volatile and therefore hard to forecast correctly.

Although the lead-times are relatively short, during promotions the delivery is still not fast enough to prevent the misses. This is mainly because the timings of the various processes (sharing of forecast, ordering and subsequent delivery etc.) are not synchronized. When the lead-times are this short (X), the lead-times are subject to the exact timing of the order process. Because the processes do not occur at the right time of day, what effectively happens is that the lead-time of X gets another 24 hours extra. This is not a problem during regular weeks, where the demand is low and constant over time. In this case these extra 24 hours will not be noticed, since the safety-stock (of 7 DOH) is more than enough to cover this discrepancy. However, in promotion weeks this pitfall becomes painfully clear. There are several solutions to this problem, which will be discussed in the next section.

Inventory

Looking at the KPI inventory, the conclusion can be short. There is too much inventory in the supply chain, especially when comparing the total inventory to the lead-times of the material flow. Technically, without the bullwhip effect, a total of 2 to 4 DOH should be enough to cover the consumer demand. This is of course in an ideal world; something that might never be achieved.

If one tries to explain the inventory levels at the various points in the supply chain, it is possible to identify a few root-causes behind the numbers.

Inventory at the Retailer X store

There is a lot of inventory in the stores of Retailer X. This has one main reason, namely the fact that the stores want to maintain a good "store image". The shelves need to be filled to make the store attractive for the customer. These shelves have a capacity that is much larger than the purchase of the goods, resulting in high stocks.

One could say that the shelves need to be decreased, but smaller shelves mean less visibility in the stores, resulting in lower sales. This is of course something that the manufacturer wants to avoid. Therefore one should ask himself if it is really a bad thing that there is a lot of stock in the stores. Dreft ADW is a product that does not perish quickly, thus if the shelves are stocked with goods, there is no real downside to having a large stock in the stores of Retailer X.

Inventory at the Retailer X DC

The inventory levels at the Retailer X DC are relatively good. The VMI agreement is respected by Procter & Gamble and no big problems arise in the inventory at the Retailer X DC. When comparing the performance of the KPI Inventory with Service, one could say that the problem with the inventory at the Retailer X DC is that there is not enough stock. However when compared to the lowest possible lead-time, seven days of inventory should be more than enough. Trying to solve the problem with the service levels by just putting more stock on ground at the Retailer X DC is not a sustainable solution.

Inventory at the Procter & Gamble DC

Objectively, the main problem with the high levels of inventory lies at the Procter & Gamble DC. An analysis on the safety-stocks of the various SKUs showed that these are too high, resulting in enormous amounts of inventory that take a long time to be cleared. The total days on hand of X days might even be regarded on the low end, as the existence of promotion weeks drive this number down. Looking at the DOH in regular weeks only, one gets close to X DOH. It must be noted here that weeks after promotions regular sales are not lower than weeks not around a promotion.Of course one of the drivers behind these safety-stocks is the SAMBC. The general tendency is to increase stock whenever the service levels are down. The analysis showed, however, that the problem does not lie in the availability of products. Therefore, one could ask the question whether the safety-stocks are unnecessarily high.

Apart from the fact that the safety-stocks are quite high, relative to the purchase of goods, the inventory levels are also very dependent on the minimum batch sizes that the plant retains in their production cycles. Small batches result in a large number of change-overs, which have high costs. The batch sizes are to a certain extent SKU dependent, however for each Dreft ADW SKU, the minimum batch size is determined to be 1000 cases. When this is compared to a total purchase of cases of approximately 1000 cases a week distributed over 15 SKUs, it can be concluded that this might not be the best minimum batch size.

A third problem that could be identified, was the outdated information on sales forecast that was used when planning the production. Although this information is updated daily (especially for promotions), this data is not used by the production plant.

The use of out-dated information

The initial forecast of a promotion is 10000 cases, this information is shared with the production plant and a production planning is made based on this information. However when the forecast is adjusted by Retailer X to for example 7000 cases, this is communicated with the Order Management who adjusts the replenishment of the Retailer X DC. This information is however ***not*** *communicated to the plant, resulting in an overproduction of 3000 cases*

Thus the safety-stocks and minimum batch sizes need a thorough re-evaluation to detect whether the total inventory in the Procter & Gamble DC can be diminished.

Sub-conclusion

The problem in inventory lies not with Retailer X's part of the supply chain. Procter & Gamble has the biggest opportunity when it comes to bringing down the inventory in the chain. For this, a thorough re-evaluation needs to be done on both the safety-stocks that Procter & Gamble retains as well as the minimum batch sizes of the production Plant.

Costs

An in-depth data analysis on the total supply chain costs could not be done, because this data was not available. The analysis that could be done (on the processes in the material flow of Procter & Gamble) showed that the largest costs are incurred by the storage of the products in the Procter & Gamble DC. This confirms the suggestion that there is a too high inventory in especially the DC of Procter & gamble.

In the next section we will discuss solutions to the above explained problems.

4.8. Identified possible supply chain interventions

Now that the problems and shortcomings of the current supply chain of Dreft ADW have been identified, the focus will move to solving the problem in a sustainable way by implementing changes that follow from the concepts of vertical supply chain collaboration.

An expert session was arranged to identify possible solutions to the problems that were identified in the supply chain. The people that were present at this workshop were:

The day started with a presentation of Procter & Gamble and the production plant in Mechelen. After this introduction, the academic background behind collaboration in the supply chain was shortly explained to the attendants. This provided some support and context for the line of thinking in achieving the goal of the day; identify solutions to solve current state problems in the end-to-end supply chain. The next session was a presentation on the findings of the data analysis on the current state of the supply chain. The initial data analysis on the current state of the supply chain served as the input for the brainstorm session to identify and think of solutions for the problems that surfaced during this analysis.

After the value chain analysis was presented to the attendants, a brainstorm session started on how to improve the supply chain together; Procter & Gamble and Retailer X. In a plenary session everyone could bring their ideas to the table. With post-its these ideas could be placed on a large poster of the (in Figure 6 showed) overview of the Dreft ADW supply chain, next to points in the supply chain where the improvement should be made.

The initial data analysis showed (amongst others) two biggest opportunities for both Procter & Gamble and Retailer X:

1. Large volume misses can be prevented, especially during promotional weeks. According to the data, more than X % of all misses in a year are during the 10 promotional weeks. Misses occur for the largest part on the replenishment cycle on Tuesdays during a promotion. This can be explained by the fact that on the Tuesday replenishment cycle of the stores of Retailer X, the uplift is taken into account. However Procter & Gamble gets this uplift on Tuesday morning, resulting in a too late replenishment of the Retailer X DC. In summary, service levels can be improved by aligning replenishment processes.
2. Another key finding is the large stock at the Procter & Gamble DC. This has several causes, but most importantly, because several safety factors are used throughout the chain (Retailer X uses a safety factor in their store demand forecast, Procter & Gamble Order Management and Supply Planning use safety-stocks to cover potential fluctuations, Procter & Gamble Demand Planning uses another safety mark-up in the demand forecast), resulting in excessively high stock levels.

Connectivity & Synchronization – Information Process Alignment

The first scenarios are related to both the connectivity between the order processes of Retailer X and Procter & Gamble and synchronization of those order processes. When looking at the different order (and respective delivery) timings throughout the day, there is a large opportunity in aligning the various processes. The lead-time of the complete supply chain is already rather low, but there still lies an opportunity in the order timings. In an ideal situation the processes are aligned in such a way that, whenever a truck arrives at point A, it will be shipped almost immediately to point B and so on until it reaches the store.

In the current state, a large part of the misses (thus responsible for the low service levels) is due to the fact that the information processes are not aligned. In regular weeks the sales volumes with respect to the minimum order quantities are so low that this misalignment is not a real problem. However during promotional weeks (high sales volumes) this problem becomes apparent. Due to the misalignment on Tuesday replenishment in a promotion week, cases are missed and service levels take hits.

In the current situation, Retailer X starts picking at their DC for the replenishment of the stores at x hours. However, because the replenishment of Procter & Gamble is released at x hours in the morning, the truck arrives that day at the Retailer X DC at x hours; effectively adding one day to the lead-time of X, thus resulting in missed cases. During promotion weeks this becomes painfully clear as an uplift in sales cannot be covered in the current process. On top of that, the information on the magnitude of the uplift is already available on Monday afternoon, thus these missed cases would not have to occur! Especially with such short lead-times, process alignment is of vital importance to fully leverage the agility of the supply chain.

Solution 1 – Monday afternoon Promo release

This first scenario was proposed during the workshop and can be implemented without any large implications on the course of current events. This scenario proposes an extra Monday afternoon order release during the promotional weeks. This would trigger an extra replenishment of the RETAILER X DC before Tuesday afternoon.

In this solution, there is only a minor change with respect to the current situation. All processes will be performed in the same way as in the current state. However, there is an extra order release on Monday afternoon during a promotional week. According to the Store Demand Forecasting department of Retailer X, the final demand forecast for the promotion is available at X hours on Monday afternoon. To implement this solution, the Order Management department of Procter & Gamble will have to make contact with Retailer X to update their Store Demand Forecast for the upcoming days at X hours and do another order release on Monday afternoon. This triggers a replenishment of the Retailer X DC before their new picking round on Tuesday, greatly reducing the chances of misses during the promotion. In the figure below a schematic overview is given for this alignment.

Because the order release is on Monday afternoon, there plenty of time for all parties involved to still perform the needed actions for replenishment without working overtime. The actors involved in this extra order process are the Customer Demand Forecasting department of Retailer X, the Order Management Department of Procter & Gamble, a third party responsible for transportation and the departments responsible for the warehouse operations of both Procter & Gamble and Retailer X. As the activities in the various DCs are already running 24/7 and the order release occurs in general daily working hours, no extra costs are incurred with implementing such a scenario.

Solution 2 – Full process alignment

This scenario sketches a world where the supply chain, from the consumer to the plant, is completely synchronized when it comes to order process timings. The consumer buys the finished product throughout the day and at the end of the day, the order process is triggered. This solution requires a rather long-term view on the future state of the supply chain. One of the implications that this solution to the KPI problems puts forward, is that it requires all the various actors in the supply chain to better connect with each other. The stakeholders will need to collectively come to an optimal ordering schedule to optimize picking and delivery timings.

To sketch an example: replenishments of the stores needs to occur in the morning, just before the consumers will start buying their products. Dependent on the lead-time of the store to the DC of Retailer X, this bootstrap will require the Retailer X DC to start picking at a certain time. Right before this, the replenishment from the Procter & Gamble DC needs to arrive. Complete alignment of all processes throughout the chain would ultimately yield great improvement possibilities for both KPIs; Service and Inventory.

Contrary to the first solution, which is a more easy to implement variant of this solution, it will take a lot more effort to completely synchronize the supply chain as described in the previous paragraph. First of all, the supply chain stakeholders will need to agree on the fact that collaboration is indeed the way to go. Then the processes need to be compliant (same data processing tools or at least compatible). Without going into too much detail (this will be done in a later chapter), a quick look at the current supply chain, some ordering processes will need to be done at night. This will either increase fixed costs for hiring night shifts (in case manual intervention or manual processing), or an investment in automation is needed.

Synchronization – Batch size

Solution 3 – Production batch size reduction

Maybe not directly related to vertical collaboration, this solution focuses on solving the problem of high inventory levels at the Procter & Gamble DC. Next to that a (less apparent) benefit of reducing the batch size is the fact that it might increase service as production is more tailored to the needs of the customer (smaller batches and higher replenishment frequency).

The solution is very simple. Currently the minimum batch size is roughly 1000 cases, with production runs of often much higher amounts. Reducing the minimum batch size would yield a more precise production, relative to the demand of the customer, which would result in lower inventory and probably higher service levels.

Visibility – Availability of real-time information

The second concept that is used as a basis for possible solutions, is the visibility of information. The data analysis showed that the various departments in the supply chain use safeties, whether it is in the forecast of possible sales or in safety-stocks, to not miss shipments. Taking out these safeties should result in lower inventory levels at Procter & Gamble and Retailer X DCs.

Solution 4– Sharing of Point Of Sales (POS) data

The fourth solution to the high inventory levels and the low service levels is the sharing of POS data. Research has shown that the bullwhip effect can be reduced by sharing clean, unchanged, sales data throughout the chain (Chen et al., 2000; Fransoo & Wouters, 2000; Lee et al., 2004). Usage of this data by the various departments that are responsible for getting the right amount of product at the right place at the right time (replenishment and supply) will cause the chain to be more agile and lean. No unnecessary safety-stocks or over-estimation of the promotion forecast will be the result.

In theory, implementing this solution sounds like an easy task, but might be a lot harder than expected in real-life. First of all, the retailer Retailer X will need to share sensitive information with a, although not direct, rivaling company. This first step will depend heavily (if not completely) on the willingness of the retailer. Moreover, some sort of a computer system to transfer the POS data is necessary. As there are lots of retailer stores, processing this data will require a lot of computing power, especially if one would like to use real-time data in their processes. Subsequently there needs to be a standard in the format of sharing data, so the POS data can be universally shared and processed by the different actors in the supply chain.

In short, there are a lot of uncertainties and it takes the cooperation of a lot of stakeholders to effectively move to a supply chain where real-time point of sales data is shared throughout the supply chain. On the short-term, no real-time POS data on all products will be made available, simply because the IT structure cannot supply this at this point in time.

In the specific case of the retailer Retailer X, they offered the possibility of providing Procter & Gamble access to their new order management platform that calculates the Store Demand Forecast. This would allow Procter & Gamble to ***access*** update SDFs 4 times a day; instead of the ***possibility to receive*** the SDF four times per day. This is a first step in complete visibility of real-time information, but there is still a long way to go. With the help of a scenario analysis, the state of visibility in the supply chain in 5 to 10 years will be sketched.

Transparency – Use of available up-to-date information

The third concept in vertical collaboration is supply chain transparency or "the outreach of available information". The data analysis on inventory levels showed that, although an up-to-date SDF was available at Procter & Gamble, the production plant did not update its production plan accordingly. This resulted often in overproduction.

Solution 5: Use of up-to-date (available) information in the plant

Nowadays, the plant receives the initial promotional forecast and plans the production in accordance. No updates in the production schedule are made on the basis of the actual sales or new SDFs. This might cause severe over- or underproduction. Overproduction will lead to the high inventory levels that can be seen from the data analysis. Underproduction is less of a problem, because the plant in Mechelen has the ability to produce-to-order. This solution would therefore specifically focus on reducing the inventory on the side of Procter & Gamble.

Implementing usage of the up-to-date SDF in the plant requires two alterations in the current processes. First, the IT structure will need to be changed, to a state where the SDF that is received by Procter & Gamble is automatically transferred throughout the chain, all the way to the production plant. Next to that, a change in the executing processes of the production planners needs to occur. The planners will need to trust the outcomes of a computer that updates the production needs.

Focusing on the long-term plan, the goal is of course not that the SDF is shared, but that ultimately the production is planned according to the actual sales. The extent and uptake of transparency in the supply chain of Dreft ADW is therefore dependent on how the future will evolve.

Willingness – ease of implementation

Although not independently included in one of the interventions, the concept of willingness sure is present in all of them. Each intervention needs a certain willingness from the relevant stakeholders to be implemented. When looking at the different interventions, a conceptual graph can be sketched that plots the difficulty of implementation versus the degree of willingness. This graph is shown below.

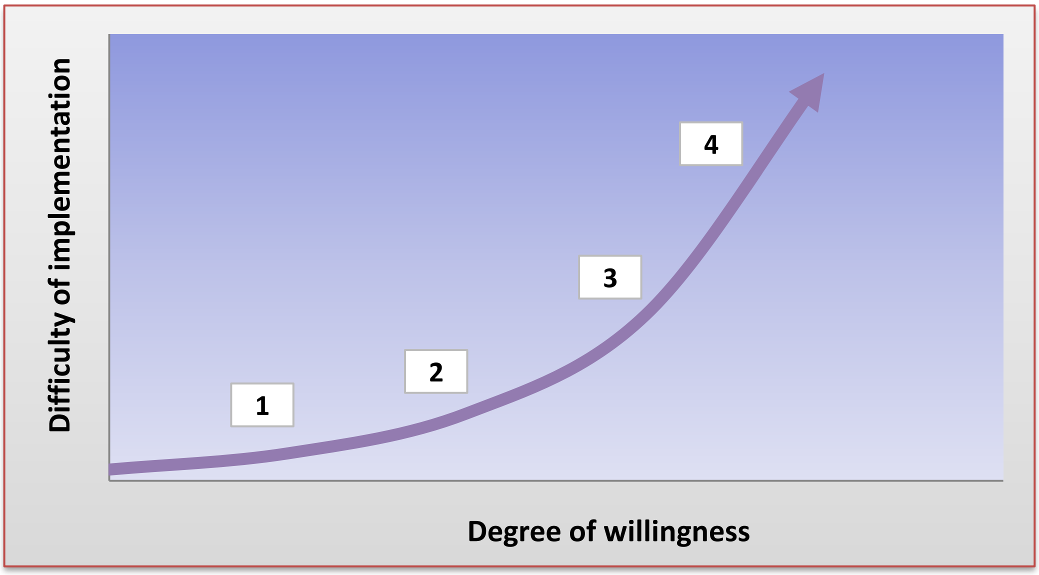

Figure 14: Conceptual graph of impact of willingness on the ease of implementing vertical collaboration

The graph places the different interventions in an order that could be used undertake these interventions on a step by step basis. The order of the interventions is:

1. Implement a Monday afternoon order release during promotions
2. Use up-to-date available information in production planning
3. Fully synchronize order & replenishment information process timings
4. Provide and use POS-data throughout the chain

The choice for this order is based on the fact that for each step forward, either more stakeholders are involved, or the stakeholders get more affected by the action. Therefore, each step forward would demand more willingness from the stakeholders in the supply chain to enhance collaboration.

4.9. Preliminary conclusion

To conclude this chapter an overview of the data-analysis will be presented. We can conclude that the current state of the KPIs, as shown below, is far from optimal.

Although easier said than done, a few solutions have been presented for the problems in the KPIs. These solutions do all fall under the subject of vertical collaboration in the supply chain. Short-term and long-term solutions have been presented and will be used to identify a roadmap to a future state of the supply chain, where a high degree of vertical collaboration causes the chain to become the success it could be.

To quantify the benefit on the KPIs of implementing these (short-term) solutions might have on the supply chain of Dreft ADW, a computational model will be made of the supply chain. The goal of this model is to predict and quantify the implementation of the solutions, thereby better leveraging the potential of the current supply chain. A scenario analysis will provide the external surroundings that the supply chain will be subject to and will provide an assessment of the extent of implementation of vertical collaboration in the coming years.

To be able to make such a model, an identification of the stakeholders in the supply chain needs to be done. The stakeholder analysis will give an overview of all the stakeholders in the supply chain of Dreft ADW. The stakeholder analysis will then provide the information needed to make a computer model that approaches reality.

5. Stakeholder Analysis

As this research is aimed at providing an insight in the quantitative effect of creating more vertical collaboration in the chain, we are also interested in who are affected when we create more collaboration. Therefore, a stakeholder analysis will be carried out. A stakeholder analysis aims to *"evaluate and understand stakeholders from a perspective of an organization or to determine their relevance to a project or policy"* (Brugha & Varvasovszky, 2000). Keeping this definition in mind, we will try to identify the relevant stakeholders in our project, as these stakeholders will be given an important role in the modeling phase of the project.

On a top level, we can identify a few different actors that all play their own role in the supply chain. Table 6 shows these different actors and their specific roles in the supply chain.

Table 6: Actor overview

Actor	Role
Consumer	The end consumer buys the product Dreft ADW and uses it in their dishwashers. Might have a specific interest, but the main interest of all consumers is to clean their dishes in their dishwasher. To be able to do this the consumer buys dishwashing products in retailer stores.
Retailer X	Retailer of Dreft ADW products from the manufacturer Procter & Gamble. Sells the product to the consumer. They have an agreement with the manufacturer that they will sell their product in their stores.
Procter & Gamble	Manufacturer of Dreft ADW and sells these to the retailer (amongst others: Retailer X). This actor needs to make money by selling as many products as possible. They have agreements with downstream actors that they will supply their need of products and agreements with upstream actors that they get supplied with the needed raw materials
Third Party Logistics Company	Provides transport between the various actors in the supply chain of Dreft ADW. These companies are hired to transport goods from one place to another. Their main goal is to make money by getting as much orders as possible.
Raw Material Supplier	Mines the raw materials and produces the chemicals that are used to produce Dreft ADW. This actor wants to sell as much raw materials as possible to the manufacturers.

A complete mapping of all the stakeholders within these actors will provide the insights needed to determine which stakeholders have which part in the not optimal functioning of the supply chain. The identification of all the stakeholders will provide the basis on which stakeholders become incorporated in the computer modeling phase and to what extent certain stakeholders will be grouped or left out.

In the next section all the stakeholders will be discussed briefly per actor. We will thereby focus on the last three actors in the supply chain:

- Consumer
- Retailer (Retailer X)
- Manufacturer (Procter & Gamble)

At the end of this chapter a more detailed analysis will be done on the specific stakeholders that have an important role in the supply chain of Dreft ADW. These stakeholders will then be described in more detail.

5.1. Stakeholder identification

In this section we will describe in short the stakeholders within the first part of the supply chain of Dreft ADW on a more detailed level.

Consumer

The consumer can be seen as a stakeholder on its own. When using the definition of the stakeholder by Stanford Research Institute *"those groups without whose support the organization would cease to exist"*, the consumer is vital for the existence of the retailer, manufacturer and raw material supplier. If the consumer does not buy the products, all these actors will cease to exist and with them the various stakeholders that they exist of. According to the marketing department of Procter & Gamble, the consumer of Dreft ADW can most easily be described in the following groups:

- Brand sensitive – non brand sensitive: Dreft ADW is a strong brand, preferred over other brands by a solid part of the consumers. However, this amount of consumers remains limited as most consumers are little brand sensitive and will buy whatever is available on the shelves.
- Promotion getters – regular consumers: This segmentation quite closely relates to the first one. It can be seen that more than X% of the sales are done during promotions, pointing to consumers who endeavor buying their products during promotion periods. The brand sensitive consumers will buy their desired product during a promotion and try to stock up until the next promotion. The non-brand sensitive consumers will buy whichever is on sale.

The main interest of the consumer is often to buy the right product versus the (in their eyes) right price.

Retailer X

Together with Store Replenishment, this department is responsible for guaranteeing the supply of Dreft ADW to the stores. The consumer demand forecast is translated into one total store demand forecast, in combination with the actual inventory levels of the stores and the Retailer X DC. This department receives business intelligence on promotional forecasts and can translate this into the store demand forecast.

Stakeholder: Commerce

This department makes a long-term forecast on promotional sales. The people in this department have business intelligence on the sales during specific promotions and try to predict the total sales in such promotional weeks correctly.

Stakeholder: Store Replenishment

This department receives the total store inventory of Retailer X stores and arranges the shipping of the finished Dreft ADW products to the Retailer X stores across the country. Relevant properties are the knowledge on total store inventory and the supply practices of the stores.

Stakeholder: Capacity Planning

The Capacity Planning department arranges the activities around the inbound Dreft ADW products at the Retailer X warehouses. Relevant properties are the knowledge about inbound and outbound flows of products in the Retailer X DC.

Stakeholder: Warehousing IN

Just as the Warehousing IN department of Procter & Gamble, this department is responsible for all inbound logistics in the Retailer X DCs. The department unloads the arriving trucks and places the pallets in the right place in the warehouse.

Stakeholder: Warehousing OUT

Just as the Warehousing OUT department of Procter & Gamble, this department is responsible for all outbound logistics in the Retailer X DCs. The department is responsible for picking the right products for the right transports. The department then helps in the loading of trucks that are sent to the stores

Stakeholder: Store IN

Just as the Warehousing IN department, Store IN is responsible for all inbound activities, but in this case the inbound activities of the Retailer X Store. The department unloads the trucks and places the products on the shelves in the stores.

Procter & Gamble

As a huge multi-national with a wide range of products, Procter & Gamble is a FMCG company. While their core competencies lie in the detergent products, Procter & Gamble owns strong brands like Dreft (Fairy), Ariel, Pampers, Gillette, Braun and various others. As stated before the company wants to sell Dreft ADW against the highest price and with the lowest costs (they want to make profit). Below in short the various departments that play a role in the supply chain of Dreft ADW are briefly discussed.

Stakeholder: Order Management

This department of Procter & Gamble handles all orders from Retailer X. As Procter & Gamble is a Vendor Managed Inventory Partner of Retailer X, the department receives Store Demand Forecasts and Retailer X DC inventory levels and translates these into product demand. Relevant properties are the knowledge/control of Retailer X DC inventory policies (inventory levels & dock capacity) and store demand forecasts. Without the Order Management department, no products would arrive at the Retailer X DC.

Stakeholder: Supply Planning

The Supply Planning department combines product demand and Procter & Gamble inventory data into one supply demand. Relevant properties of this agent are the knowledge on inventory management and validity of product demand.

Stakeholder: Demand Planning

This department is responsible for merging supply demand (from the supply planning dpt.) and sales forecasts (from the commerce dpt.) into one demand forecast that is communicated to the Production Supply & Planning. Relevant properties are knowledge on validity of forecasts.

Stakeholder: Commerce

This department communicates with the Commerce department of Retailer X to form an overall sales forecast and try to do this as correctly as possible. Relevant properties are knowledge on promotional weeks, out of the ordinary fluctuations in sales, concrete/direct (personal) links with the retailer (Joint Forecasting).

Stakeholder: Demand Requirements Planning

The Demand Requirements Planning department transforms demand of various markets (demand planners) into 1 production demand. The department has the capacity to bundle various streams of information.

Stakeholder: Transport Operations

This department is in charge of arranging shipping of the finished Dreft ADW from the Procter & Gamble DC to Retailer X DC. Relevant properties are the knowledge on short and (mid-) long term transports. The department contacts the third party logistics company for the physical transport.

Stakeholder: Production Supply & Planning

This department of Procter & Gamble is responsible for the production orders to the plant production department. It selects the mode of operation (i.e. which Dreft ADW SKU) and throughput based on the demand forecast that is received. Relevant properties are knowledge on production planning and scheduling systems.

Stakeholder: Production

This department is responsible for the actual production of the Dreft ADW goods from the raw materials. Relevant properties are the knowledge of operating the production plant managing the in-flows and stock of raw materials.

Stakeholder: Warehousing IN

This department is responsible for the unloading of shuttle transport from the plant to the Procter & Gamble DC and storage of the finished goods in the Procter & Gamble DC.

Stakeholder: Warehousing OUT

The warehousing out department is responsible for guiding the activities around loading the trucks that leave for the Retailer X DC. This includes picking, customization and other activities that need to be done before a truck can leave for the Retailer X DC

5.2. Stakeholder Segmentation

In the previous section all relevant stakeholders in the supply chain of Dreft ADW were identified and shortly described. However, not all of these stakeholders might be relevant for our research objective. The research objective clearly states that we are looking for a tool to measure the impact of collaboration in the supply chain on the KPIs. Therefore the relevant stakeholders should be the ones that are being affected when collaboration is increased. To be able to do this we will make use of the technique stakeholder segmentation, which aims on grouping stakeholders based on common attributes so as to identify which stakeholder really counts (Mitchell, Agle, & Wood, 1997).

Looking at the mapping of the supply chain, various departments within the different actors are responsible for processing and interpreting all kinds of information streams. As explained in the short descriptions above, some stakeholders collect and bundle the data, some change the information, some collect different kinds of data and others only check the information that is passed on to the next stakeholder or do not even handle any data. In the figure below, a segmentation is made based on these criteria; use or transformation of information and material or information flow.

We have identified the most relevant stakeholders of the Dreft ADW supply chain to be:

- *Consumer Demand Forecasting Department*
- *Store Demand Forecasting Department*
- *Store Replenishment Department*
- *Order Management Department*
- *Supply Planning Department*
- *Demand Planning Department*
- *Production Planning Department*

With these stakeholders, it should be possible to design a model that correctly depicts the supply chain of Dreft ADW. In the rest of this chapter we will therefore analyze in more detail what the specific processes are within these departments.

5.3. In-depth Stakeholder Description

To be able to make an accurate model, the choices and actions of various persons/departments within the supply chain need to be mapped. Based on this mapping, the important agents and the relevant processes in the supply chain can be identified and used as building blocks of the model. A current state mapping of the supply chain is given in Appendix C. In this figure the various departments responsible for a certain process in the supply chain of Dreft ADW are displayed. In this section each department/process will be decomposed to describe on a "micro-scale" what choices are made by people that influence the supply chain. The information is gathered through ***unstructured interviews*** with the relevant people within each department.

Retailer X

As described in the introduction, on a top level the supply chain is composed of three actors that make the product and are responsible for getting the finished product to the consumer. These three actors are: the retailer (Retailer X), the manufacturer (Procter & Gamble) and the raw material suppliers. In this section the departments and processes at Retailer X, with respect to the supply chain of Dreft ADW, will be discussed.

increase in production. For example, whenever there is a huge uplift in the sales forecast for a certain product this can be observed.

Demand Planning (DP) & Demand Requirements Planning (DRP) department

Interview conducted with: Axel Aardoom, Business Planning Leader FBNL

The interview on the Demand Planning department and Demand Requirements Planning are combined into one, as these departments do not focus on a Customer-Product combination. As already explained in the Supply Planning department, the further away up-stream one moves in the supply chain, the larger the scale is on which the departments work. This is a logical consequence of the fact that there are many consumers (consuming 1 bag of Dreft per month) that all need to be supplied by often one or a few plants (producing thousands of cases per day).

The DP and DRP departments are responsible for ensuring ***long-term supply*** of the Procter & Gamble DCs. The departments aggregate the demand of all selling markets and make a forecast of this demand for the upcoming month. This is again a larger scale than the supply planner, as the demand planners provide the main input for the production based on the aggregated demand of all supply planners of different products and different markets.

Basically what a demand planner does is that he collects and aggregates the needed supply information of the different supply planners and uses the business intelligence (long-term promotions, upcoming events etc.) acquired from the commerce department as input for the total demand forecast. This demand forecast is then uploaded in the computer tool SAP; making the demand visible for the production teams in the Plant. Next to that, each day between X and 12:00 there is a conference call with the DRP planners and the production team for any manual interventions (sudden increases in the demand). To make the processes of the Demand Planners clear, an example of the Dreft case is given below:

At the beginning of the month, the forecast of all regular sales of Dreft (for all retailers) is made based on the sales history. Moreover, the forecast of the various promotions of various retailers is communicated to the demand planner. In the case of Retailer X, the final forecast of a promotion is shared four weeks before the promotion. The aggregation of all promotions and regular sales of all retailers in a certain market results in a monthly demand for a certain product, which is then uploaded in SAP. Daily calls ensure that sudden (expected) uplifts are communicated to the plant.

It must be noted here that the Demand Planning Department uses a safety factor of 1.2 in the demand forecast to ensure no out-of-stocks occur at the Procter & Gamble DCs.

Production Supply and Production Planning

Interviews conducted with: Laurent Haenecour & Wim Depaepe, Mechelen Site Production Planners

Just as the DP and DRP departments, the production departments can be regarded as one. The operators in these departments sit together and have a standard process that is being repeated each morning to establish the production cycle of the upcoming 24 hours. The departments combined are responsible for translating the demand into actual production, ensuring that no out-of-stocks occur in any Procter & Gamble DC that they supply. This is a partly automated, partly manually guided process recurring each morning.

Every morning, Laurent Haenecour looks in SAP to see which product will run OOS in the near future. This “near future” depends on the product and the place of the DC (which is of course related to the lead-time). In the case of Dreft, if production needs to be done immediately, this is 3 days. Based on this analysis, he will mark the urgency of production for the different products in his portfolio.

So if, for example, according to demand the stock of Dreft will drop below the safety-stock (determined by the Supply Planner) in the next three days, there is an urgency to produce more Dreft today. However if it will run out in two weeks, producing Dreft is less urgent, but can be done if a gap in the production schedule is present. This rating of urgency is done for all sorts of products and various timings (dependent on DC and product).

Next to that, each morning at X there is a conference call to check whether the forecast for the upcoming days is still correct or if there are any big changes that cannot be covered by the safety-stocks of the various DCs and trigger immediate action from the production team. After this call, Laurent Haenecour knows where problems might occur and communicates the urgent production needs to Wim Depaepe.

Wim Depaepe makes the production schedule. Each day at 12 o'clock (when Laurent Haenecour finishes his call) he locks the production schedule for the next 24 hours. This schedule is based on the input of Laurent Haenecour (the urgent product codes) and the input of SAP. SAP automatically makes a production schedule for the next 90 days based on the demand forecast data (uploaded by the demand planning departments). This schedule is manually adjusted to the urgent needs, resulting in the final production schedule. At 13:00 hours this schedule is locked and production for the next 24 hours will occur according to this schedule.

Some restrictions to the production schedule: in the case of Dreft, the minimum production batch size at the moment is 1000 cases and lead time between the production and delivery at the Procter & Gamble DC is 36 hours. So if a production of Dreft is taken into account in the production schedule of Monday, it will be available at the Rumst DC on Wednesday night at 1 o'clock.

5.4. Preliminary Conclusion

To conclude this chapter, a conceptual model design is presented on the basis of the in-depth stakeholder analysis. At the bottom of this page, in Figure 16**,** this conceptual model is presented. The conceptual model can be regarded as the primary flow of information; the flow of materials is not displayed. The consumer generates the consumer sales data, which serves as the primary input for the supply chain.

The conceptual model is buildup of the following actors (grouped stakeholders):

- Retailer X Replenishment: this is a name for the joint departments of Retailer X who are responsible for the right replenishment of the stores. These departments include the Customer Demand Forecasting, Store Demand Forecasting and Store Replenishment departments.
- Procter & Gamble Order Management: the department is responsible for maintaining the right inventory levels at the Retailer X DC
- Procter & Gamble Supply Planning: the supply planning is responsible for maintaining the right inventory levels at the Procter & Gamble DC.
- Procter & Gamble Demand Planning: made up of both the Demand Planning and the Demand Requirements Planning department, in the conceptual model the demand planning is responsible for generating a production demand.
- Procter & Gamble Production: this actor is a collective noun for both the production supply planning and the production planning department of Procter & Gamble. The department is responsible for triggering the complete production of Dreft ADW.
- Raw Material Supply: the raw material supply (identified as one actor) is responsible for the supply of Dreft ADW raw materials to the production plant.

6. Dreft ADW Supply Chain Design Space

The stakeholder analysis in the previous chapter provided valuable insights in the relevant actors and their actions in the supply chain of Dreft ADW. In Figure 16 of the previous chapter a graphical representation of these stakeholders and their relations is given. The current chapter aims at working towards the formalization of the problem by discussing major Dreft ADW Supply chain design choices.

As the conceptual model will be translated into a computer simulation model, the characteristics of the model design that will be made in this chapter should be translatable into a computer model. The first section of this chapter will therefore be a discussion on which class of computational modeling should be used to simulate and measure the effects of vertical collaboration in the supply chain. Subsequently the other selection criteria and design choices are being discussed.

6.1. Computational modeling choice

In the previous chapter an in-depth stakeholder analysis was done. As can be concluded from the stakeholder analysis, the supply chain of Dreft ADW is a large and rather complex multi-actor system. As is common in large multi-national corporations, the companies are unwieldy with slow decision making processes. This causes the problem that for practically every single department the daily processes of ordering and supplying the product are cast in concrete. Large changes in these departments will be hard to implement and/or will take a long time to implement.

The data-analysis showed that the biggest opportunities lie in the KPIs service and inventory. Clear problems can be identified that might be solved when implementing the concept of vertical collaboration in the supply chain. Creating more visibility, interconnectivity and transparency together with synchronizing the supply chain, will certainly have a positive impact on the KPIs. During a work-session with industry/supply chain experts some possible (short-term) improvements were identified. To be able to estimate the effect of these solutions on the KPIs, it was decided that computer modeling would be the right tool to use. By deciding that the next step should be modeling of the supply chain and subsequently analyzing the proposed (process) improvements, a conceptual model of the important actors in the supply chain of Dreft ADW needs to be made that could easily and correctly be translated into a computer model.

Looking at the different stakeholders in the supply chain, it cannot immediately be seen which stakeholders have the most influence on the KPIs. It is assumed that those stakeholders who influence the flow of information are in the end the most directly responsible for not meeting the KPIs. According to the data analysis it is these departments that can either make or break the KPIs. The departments with a more executing role might also have an influence but this can often not be attributed to a single or set of recurring root-causes. Therefore the conclusion of the stakeholder analysis yielded a conceptual model that was based on the flow of information and could be used to transform into a computer model. Thus the question rose, what kind of modeling tool can best be used to describe such a complex multi-actor system where many stakeholders act according to their own rules?

When making a choice for the modeling tool, there are many suitable alternatives. Some initial requirements of the modeling tool should be that it is suitable for modeling multi-actor systems, suitable for describing supply chain and be able to calculate the predefined KPIs for certain changes in these supply chains. Although various modeling tools fit these easy initial requirements (and might therefore be up for the task), the choice is fallen upon Agent-Based Modeling (ABM). Why ABM will be explained in the next section

Agent-Based Modeling

Agent-Based models are a certain type of computational models that can be used to simulate the actions of- and interactions between agents in multi-agent systems with the intention to find implications of their behavior on the whole system (Van Dam et al., 2012). Although related to multi-agent systems; ABM is often used to describe such a system. The key distinction between ABM and other multi-agent systems (multi-agent simulation) is that ABM not searches for a desired outcome, but rather provides insights in the collective behavior of a system of agents whenever a single agent changes its behavior.

In light of this research, ABM seemed an appropriate tool to model the supply chain with, as we are exploring the opportunities that lie in vertical collaboration and the benefits (or disadvantages) that come with implementing the concepts. There is no desired outcome, apart from an advice to the various actors in the supply chain to implement (concepts of) vertical collaboration. With the ABM the quantitative benefits and disadvantage of implementing these concepts can be shown. This is also the point where current research on the benefits of ABM stops.

Current research on vertical supply chain collaboration showed that the various concepts have a significant positive impact on the total supply chain performance (Barratt, 2004; Chen et al., 2000; Skjoett-Larsen et al., 2003). Very limited research has been done on the effects on the KPIs when implementing these strategies in the FMCG industry (Bottani, Montanari, & Volpi, 2010; Sahay, 2003). By using agent-based modeling, it will be possible to check the benefits of various degrees of vertical collaboration without the effort of running real-life pilots.

Agent-Based Modeling in literature

Although Agent-Based modeling has been around for a few years now, the modeling tool has only become quite popular in the last two decades due to the increase in computing power of commercially available PCs. A while back already, a rather nice paper was written on ABM, that established why ABM is useful and when ABM should be used (Bonabeau, 2002; Moyaux, Chaib-Draa, & D'Amours, 2006). The authors stated that there are three benefits to using ABM over other modeling techniques:

1. ABM captures emergent behavior
2. ABM provides a natural description of a system
3. ABM is flexible.

The article showed that ABM is most useful when applied to human systems and when applied to these kinds of systems ABM can bring significant benefits in respect to other modeling techniques. The authors stated that ABM was best used in the following cases/situations:

- ABM should be best used when the agent interactions are complex, nonlinear, discontinuous or discrete.
- When agent's positions are not fixed and the behavior space is crucial for the system.
- When each agent is potentially different (non-homogeneous systems).
- When interactions are heterogeneous and complex.
- When the agents exhibit complex behavior, including learning and adaptation.

With the rise of ABM, it became more used in (scientific) research in different kinds of scientific fields (biology, economics, social sciences, business, technology etc.). It was therefore useful to make a quick dive in the literature on Agent-Based models used in supply chain research.

Although not quite extensively applied to supply chain research, there are some relevant articles on the use of ABM in supply chains. Over the past decades, not only ABM made an entrance in the field of supply chain research. Also many other types of analytical modeling tools have been used to describe the dynamics of a supply chain. Many of these systems have however shown to be more focused on the physical realities rather than interactions between decision makers. This way of modeling does of course not take into account the socio-technical nature of supply chains. Literature has shown that, because of the socio-technical nature of a supply chain (human interactions responsible for choices in technical environments) ABM has also been used to model these dynamics. Moyaux, Chaib-Draa, & D'Amours, (2006) presented a review paper in 2006 on Supply Chain Management in multi-agent systems. They state that *"thanks to their adaptability, their autonomy and their social ability, agent-based systems are a viable technology for the implementation of communication and decision-making in real-time"* (Moyaux et al., 2006). The review paper also discusses various previous projects that made use of a multi-agent approach in researching supply chains. They made a distinction between two groups: supply chain management projects and design projects. Various projects are described and studied problems include: bullwhip effect, coordination, intra- & inter-company operations management, partner selection etcetera.

Now that the choice has fallen on ABM, the design of the future supply chain should be translatable into a computer model programmed in an ABM software package. Therefore, when making the design choices, the choice for ABM will be kept in mind. In the next sections the selection criteria, technical and institutional design components for analysis and a final overview of the design choices is given.

6.2. Selection criteria for Dreft ADW Supply Chain design options

As the goal of this research is to measure the effect of vertical collaboration on certain KPIs in a supply chain, a selection must be made of important design variations to come to a feasible set of design choices. These selection criteria are discussed below and will be taken into account in the remainder of this research. In the introduction of this report it was stated that a model will be designed for a scenario in the near future, the selection criteria have been devised with this in mind.

1. The design options must be relevant for the proposed interventions.
   When design choices are being made, it must be taken into account that the goal is to measure the effect of vertical collaboration. Interventions to test vertical collaboration in the supply chain of Dreft ADW have been proposed in the previous chapter and the model must be designed in such a way that these interventions can be tested.

2. The design choices must resemble the current supply chain of Dreft ADW for Retailer X.
   The goal of the research is to measure the effect of vertical collaboration in the supply chain. The method to do is, is by designing a model of the supply chain of Dreft ADW. Therefore the design choices should be made with goal of making a model that resembles this supply chain.

3. The design choices must have a functional effect on the stakeholders as systems.
   Central in our research are the interactions between the various stakeholders. The internal dynamics of the stakeholders are less relevant for this research. Therefore, design choices that only effect the internal dynamics of an stakeholder fall as a consequence outside the scope of this research.

4. The design options must be translatable to an ABM.
   Some options that could be included in the design are not easily translatable into an agent-based model. In such a case, it was chosen to leave such options outside of the project.

6.3. Selected technical design components

The supply chain of Dreft ADW consists naturally of several 'technical components'. Especially when one talks about information sharing, the IT infrastructure is a technical component that could have a huge effect. In this section the important technical design choices that have been made are discussed.

Information Technology (IT) infrastructure

As already mentioned in the introduction of this section, an important technical design choice needs to be made with respect to the IT infrastructure. When making a choice on IT infrastructure, in this research we do not refer to what kind of hard- or software. Rather a choice is made that is based on the limitations of the IT infrastructure in the design, thus to what extent the design needs to take the IT infrastructure into account.

Current state limitations

Opting for this choice would indicate that the IT infrastructure in the design is modeled like the current day state. This would for example indicate that access to the SDF data is hard for Procter & Gamble and production planning does not have access to up-to-date promotional forecasts.

Near future limitations

This would be a scenario where the current state limitations are in place, but with certain improvements that are already on the R&D calendar of Procter & Gamble and Retailer X. Choosing this design option would indicate that IT infrastructure will not be a limitation for the proposed supply chain interventions (as current developments in R&D are taken into account when these interventions were drafted). However it will also not be an driver for better supply chain performance.

No limitations

One possible design choice is not to worry about IT infrastructure and thereby completely discarding any limitations that come with it. One can think of, for example, real-time information and networks that incorporate all stakeholders in the supply chain. This, however, seems a rather unlikely scenario for the near future as big-data generation outruns computing power at this moment and in time horizon of this research project. By choosing this design option, it will not only not be a limitation to the supply chain performance, but also a (key) driver for better performance. For example the use of big-data in forecasting to generate a higher accuracy.

Comparison

Looking at the three options, the most obvious choice is to design the model with an IT infrastructure as it will be in the near future. This makes it possible to test the proposed interventions (as opposed to the current state of IT infrastructure), but leaves the possibilities of futuristic IT development out of the design (as this could be a master thesis on its own). In this case the first criterion outweighs the second.

Production capacity

Another important technological design choice that needs to be made is a choice on the production capacity. In many supply chains, it is often the manufacturing plant that has large limitations when it comes to creating a stable flow of materials. As the batch size is already a variable that will be under investigation, production capacity refers to the availability of production lines (or the possibility to actually produce the product). For this technical design choice there are two options.

Current state limitations

Designing the supply chain within the current state limitations, it would indicate that production is planned once a day at a fixed time. However, there is always the possibility of producing every day, so there is no limitation to the availability of production lines. What the current state limitations are can be read in chapter 5.

No limitations

The other possible design choice is not to have any limitations to production capacity. This would mean that production orders can be executed any time of day, meaning that at any time of day a production line will be ready for deployment.

Comparison

Although both options are suitable design choices, the choice has fallen on designing the model with the current state limitations. It is in this case the second selection criterion that is predominant in making the design choice. It will be rather unlikely that the production lines will (in the near future) operate under these conditions. By choosing to design the model with current state limitations (with respect to the production capacity) the outcomes of the model can be used to evaluate real-life production batch sizes.

Unloading slots at the various DCs

Another technical design component of the model is the availability of unloading slots at the various DCs. The DCs of the players involved are often very busy with hundreds of trucks arriving and leaving every day. Changes in the supply chain can lead to strains on the availability of loading and unloading slots at these DCs. Therefore it is useful to review the choices for this design component.

Current state limitations

The current situation states that deliveries from the Procter & Gamble DC to the Retailer X DC have a fixed time-frame in which trucks can arrive and unload. This is nine hours (the delivery lead-time) after the (fixed) order release timing by Procter & Gamble Order Management for Retailer X. Other loading and unloading practices at the various DCs are not bound to any times.

No limitations

In this situation there is a virtually unlimited amount of unloading and loading slots at all the different DCs. This would mean that trucks can come and go at all the DCs as they please.

Comparison

Again both options are suitable choices, but it is chosen to design the model with no limitations to the amount of unloading and loading slots at the various DCs. Just as for the IT infrastructure, it is the first criterion that is more important than the second. One of the proposed interventions depends entirely on the possibility of trucks arriving at different times than the current operations and therefore it was chosen to design without any unloading slot limitations.

Delivery lead-times

The last technical design component under investigation are the delivery lead-times. Lead-times can have a large influence on the performance of a supply chain and reducing them could have a large positive effect. There are two possible (obvious) options to choose from.

Fixed lead-times

The current state of the lead-times is described in chapter 4. The shortest possible lead-time of a case of Dreft ADW through the supply chain is X days, consisting of three steps. The lead-times are fixed for each step.

Variable lead-times

Choosing the option of variable lead-times would indicate that it is used as a variable value in the model design. It will then be a parameter that can be changed by the agents themselves or by the modeler.

Comparison

In various interviews and informal talks with various stakeholders in the supply chain, it was emphasized that reducing the lead-times was not an option. It is therefore chosen to go for option one, fixed lead-times.

Overview on technical design components

In the previous section, a disquisition of the selection of four technical design components has been presented. This resulted in four technical design component choices:

1. *IT infrastructure:* It was chosen to design the model in a scenario where there is an IT infrastructure of the near future.
2. *Production Capacity:* It was chosen to design the model in a scenario where the current limitations to the production capacity still exist.
3. *Unloading slots at the various DC:* It was chosen to design the model in a scenario where no there are no limitations to the amount of loading and unloading slots at the various DCs.
4. *Delivery lead-times:* It was chosen to use fixed delivery lead-times.

As stated before, these are the technical design components. Because a supply chain is a socio-technical system, there also need to be taken some institutional design component choices.

6.4. Selected institutional design components

This section describes the institutional design components that have been selected to be included in this research project. The choices under investigation are order business process timings, bargaining power of agents, noise in the information sharing process, safety stock and safety factor calculations and choices on the daily consumer sales

Order place, process and replenishment timings

The first and most important design component are the various order place, process and replenishment timings. There are various design options that can be thought of, but the two most probable choices have been highlighted here.

Variable timings

Variable timings would indicate that the agents themselves choose the timings on which they perform the three processes (lead-times are still fixed, so replenishment is directly related to order processing timings). Opting for this design choice would indicate that the agents are free in their actions (which would promote emergent behavior).

Fixed timings

By designing the model with fixed timings, the agents in the model can only place and process an order on fixed timings during the day. Replenishment is subsequently also fixed (as lead-times are fixed). The agents do not choose for themselves what the best time is to place or process an order.

Comparison

In light of this research the first option is the most obvious to choose. All processes are cast in concrete and in real-life it would be unthinkable that each agent chooses their own timings. From an academic point of view the second option would be the most interesting. However, as one of the selection criteria states that the choice must resemble the current day supply chain, fixed timings are chosen.

Bargaining power of agents

Another interesting institutional design choice that needs to be made is whether or not the agents have bargaining power (and if so, to what extent). One could for example think of negotiations on sharing information, maybe include costs of information.

Bargaining per order

As stated in the short introduction above, bargaining per order would indicated that the agents have some degrees of freedom in choices they make in, for example, the sharing (Retailer X) or acquiring (Procter & Gamble) of information. When opting for this choice, it should be further elaborated on what the bargaining power would really be of the agents.

No bargaining power

This choice speaks for itself. The agents do not have any bargaining power and negotiations are not included in the model design. This would indicate that, for example, POS information is freely available to anyone in the supply chain.

Comparison

This is a rather difficult choice, because both options have their upsides and downsides. No bargaining power is not a real-life situation, because Retailer X will not easily provide sales information to their upstream suppliers. However, bargaining per order is also not a feasible real-time scenario. Strategic choices on, for example, sharing of information are often made on a top management level and do not affect the agents or the interactions between them.

Ultimately the choice was made to go with option two and leave bargaining power out of the model design. It would better represent current day situation with respect to the interaction of the agents, as well as the possibility of designing a model that could (easily) measure the effect of the proposed interventions.

Noise in the information sharing process between agents

One of the key concepts that this research aims on investigating, is the sharing of (certain) information between the agents. When information is shared through any medium noise could occur, resulting in faulty information sharing. Therefore one of the design choices is whether to include noise or not.

Noise

When including noise in the information sharing process, the model should be designed in such a way that noise can be factored in.

No noise

The other choice is not to worry about noise in the information sharing process. It would then be assumed that whenever information is shared between two agents, the receiving agents receives and understands exactly what the sender intends to send.

Comparison

Including noise would mean that some sort of probability distribution will be used whether or not an agent receives the information in the right way. However, this research focusses on the benefits of information sharing, not the limitations that come with it. It is assumed therefore that information sharing is clean and no noise occurs when transferring this information.

Daily consumer sales

Another important institutional design choice is how sales are generated and distributed throughout the fiscal year. One of the important things to mention is that both promotions and regular sales are included in the model. It is especially the large gap between the sales during promotions and regular sales weeks than causes a strain on the supply chain.

Constant and fixed consumer sales
Constant and fixed consumer sales more or less speaks for itself. Comparing this to the current day real-life sales, this is only partly true. Regular sales are constant and more or less fixed, however promotional sales are highly volatile and hard predict.

Highly volatile and variable consumer sales
This is the complete opposite of the previous option. A design that incorporates these kind of sales would better match promotional sales. It is however hard to determine what the forecasting methods and models within Procter & Gamble are and how to translate these into an ABM.

Comparison
Both of these options have their benefits. It was chosen to generate the sales during regular weeks according to the first option, while the promotional sales design space will include high volatility and variability.

Safety stock calculations

The last institutional design choice is whether to leave safety stock choices up to the agents, or to give them fixed safety stocks in the model.

Fixed safety stock
With a fixed stock, historical data will be used to determine what the safety stock was when simulations are done with the designed model.

Variable safety stock
With a variable safety stock, inventory policy formulas will be used to determine the safety stock during the simulations. This would result in safety stock values that would vary with fluctuating sales, during the simulation.

Comparison
Although both options are easily translated into an ABM, the most logical choice is to choose for a fixed safety stock that is taken from historical data. The consumer sales are also taken from historical data and therefore the calculations on the right safety stock have already been performed in real-life. Choosing for variable safety stocks would therefore (most probably) not result in very different safety stock levels and would therefore not influence the behavior of the agents as entities.

Overview on institutional design components

Below an overview of the institutional design components is given.

1. *Order place, process and replenishment timings:* It was chosen to use fixed timings.
2. *Bargaining power:* It was chosen to not give the agents any bargaining power.
3. *Noise in the information sharing process:* It was chosen to design the model without any noise in the information sharing process.
4. *Daily consumer sales:* It was chosen to use fixed sales for regular weeks and volatile sales during promotions.
5. *Safety stock calculations:* Safety stock values will be fixed and taken from historical data.

Now that both the technical and institutional design components are known, it is possible to move forward and formalize the model. The next chapter will discuss the building of the modeling tool.

7. Building the Modeling Tool

This chapter describes the building of the modeling tool. In the previous chapter the modeling design is made and in this chapter this will be translated into a computer model. First an introduction will be given in which the approach of building the model will be discussed. The steps of this approach will then be discussed in separate sections. At the end of this chapter, model validation and verification will be done to assess whether the tool is representative of the current supply chain.

7.1. Introduction

Now that we have established that Agent-Based modeling is a suitable method to describe and model the supply chain to achieve the goals that were set for this project, a modeling approach needs to be found. Van Dam, Nikolic and Lukszo (van Dam, Nikolic, & Lukszo, 2012) suggested in their book on modeling socio-technical systems by ABM, a 10 step approach for identifying, building, validating and experimenting with an ABM. This 10 step approach consists of:

1. Problem formulation and actor identification
2. System identification and decomposition
3. Concept formalization
4. Model formalization
5. Software implementation
6. Model verification
7. Experimentation
8. Data analysis
9. Model validation
10. Model use

This 10 step approach will be followed to design an ABM for the supply chain of Dreft ADW and to simulate the implementation of concepts of vertical collaboration. Earlier in this document we have already extensively discussed the first two steps of this approach (and only a quick recap will be given), while step 6 through 10 will be described in the next chapter. Therefore the center of gravity of this chapter will lie at step 3 to 5; the formalization and software implementation of the model.

7.2. Problem formulation and actor identification

This step was done elaborately in chapters 4 and 5. In this section only a quick recap will be given on the research problem, the problem owner and the other actors involved.

What was the research problem?

With the data-analysis in chapter 4 we have defined that the two main problems of the supply chain of Dreft ADW are:

1. Low service levels mostly due to inaccurate sales forecasts.
2. High inventory levels due to wrong sales forecasts, too high safety-stocks and large production batch sizes.

It was devised by Procter & Gamble, before the start of the project, that an improvement in the KPIs could be achieved by synchronizing the supply chain on a vertical level *with* the retailer. These insights combined provide the basis for the modeling question. Why do we build a model? Because there is:

"A lack of insight in the effects on the KPIs of implementing various degrees of vertical collaboration (as defined in chapter 4) in future scenarios"

This problem formulation ultimately leads to the research question that is described in Chapter 4:

"Could a high degree of vertical collaboration in the supply chain of Dreft ADW lead to optimal service, cost and cash results?"

By designing modeling experiments in possible future scenarios of the supply chain, we will ultimately provide an advice on how to alter the supply chain to become more competitive now and in the future.

Whose problem is being addressed?

The problem we are addressing is actually owned by everyone in pretty much every supply chain in the world. Not a single supply chain in the world is a fully functional, fully synchronized and vertically integrated supply chain. Therefore the outcome of this research is interesting for many different actors. However, we are addressing the problem from a Procter & Gamble point of view. They issued the project and are therefore viewed as the main problem owner of this study. The study should contribute to a better supply chain design on the basis of vertical collaboration. Furthermore the work should provide general insights in KPI improvement in the future by implementing these concepts.

Which other actors are involved?

A very detailed and in depth description of the actors and stakeholders is given in chapter 8. We have defined that the actors on a top level are:

- Consumers
- Retailer X
- Procter & Gamble
- Third Party Logistics Companies
- Raw material Supplier

These actors consist of various stakeholders (who will not be described here) who are used in the next section of system identification and decomposition.

What is our role?

The model is of course a means to an end and with this study we try to gain quantitative insights in the effect of vertical collaboration in the supply chain KPIs. In this aspect, the model is therefore a tool that helps closing the knowledge gap that currently exists.

7.3. System identification and decomposition

The second step in the approach by van Dam et al. (2013) in construction of an ABM is identifying and structuring of the system boundaries and composition. This step is a rather important one as this step defines the complexity of the system that the modeler ultimately needs to translate into one model. This step defines which steps, actors and processes in the system are important in mimicking the system dynamics as a whole. Once this is defined, this stripped down simplified system can be translated into an ABM. But how to define what is important and what not?

System identification and decomposition is described by van Dam et al. as a process with two tasks with various subtasks:

1. Inventory overview: identify the physical and social entities of the system and their links.

a. Collect data, surveys, interviews and brainstorms with domain experts, stakeholders and relevant actors.
b. Chose a timeframe; select longest and shortest periods that are relevant
c. Specifically identify relevant:
    - Concepts
    - Actors
    - Behaviors
    - Interactions or flows
    - States or properties
2. Structuring phase
    a. Structuring of relevant agents and interactions
    b. Iteration to reevaluate concepts from the inventory on relevance
    c. Identifying external world

In chapter 5 we did an elaborate stakeholder analysis based on the structuring phase of the second step by van Dam et al. (2013). In this analysis we concluded that the relevant factors in describing the supply chain *in this project* should contribute to changes in the flow of information and/or directly contribute to changes in the KPIs. When implementing vertical supply chain collaboration, it would be these stakeholders that would be affected.

By the process of structuring the agents and interactions, iteration on which agents and processes are relevant, we identified the main components that would be able to describe the supply chain of Dreft ADW. For example, it is not the team unloading the trucks at a warehouse that are responsible for the inventory levels; it is the team that orders the incoming products. This yielded a system that was composed of six agents within three actors (Retailer X, Procter & Gamble and the Raw Material Supplier), with two primary data inputs (Consumer sales data and Business Intelligence), who control three inventory storage points (Procter & Gamble DC, Retailer X DC and Retailer X store). The whole system is shown in the figure below.

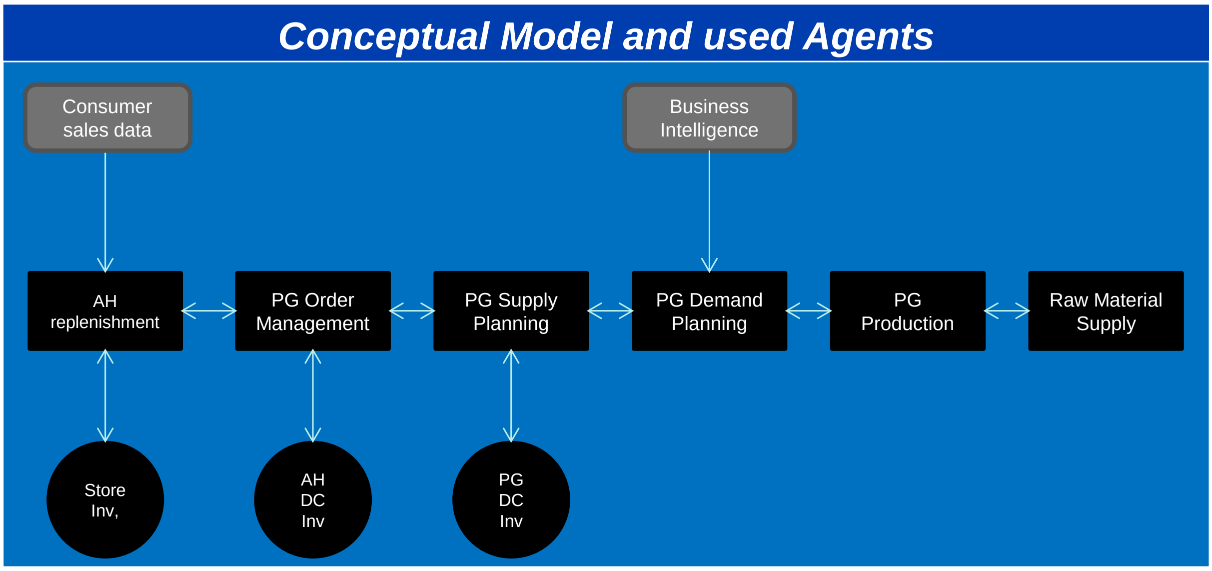

Figure 17: Conceptual model design

7.4. Agent Behavior

To describe the order and replenishment processes in the supply chain, use-case diagrams are made for the various agents in the models.

Retailer X ordering & replenishment

In the figure below, a use-case diagram of the Retailer X store order & replenishment process is shown. A detailed description on the specific actions is given in the stakeholder analysis. In this figure the processes that are used in the model are represented. This process is in short:

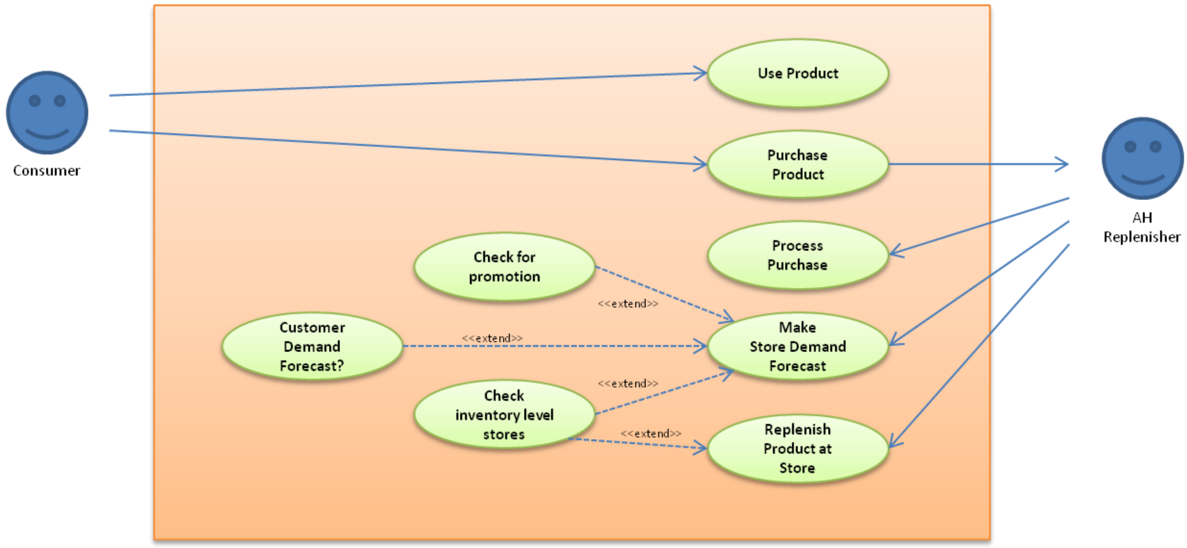

Figure 18: Use-case diagram of store order & replenishment

Whenever a consumer buys a product, this is recorded and processes by the RETAILER X replenisher to update the amount of available. The replenisher makes next to that a store demand forecast, based on the input of inventory levels at the store, a customer demand forecast that is provided/asked for and a check on whether or not it is a SDF for a promotion. The last process that the RETAILER X replenisher does in the ordering & replenishment process is the actual replenishment of products in the stores. The amount of replenishment is mainly done on the basis of the current inventory levels and store demand forecast.

Retailer X DC order & replenishment

In the ordering and replenishment process for goods at the Retailer X DC, we are looking at the interactions between the agents RETAILER X Replenisher and the Procter & Gamble Order Manager. The figure below shows the system in which Retailer X provides data on SDF to the Procter & Gamble Order Manager, who processes this SDF, checks this SDF (if necessary) and decides whether or not replenishment should be triggered (replenish product at RETAILER X DC) and the amount of product that need to be ordered at the Procter & Gamble DC (place product order). When replenishment is triggered, the RETAILER X Replenisher receives the information on the amount that will be replenished.

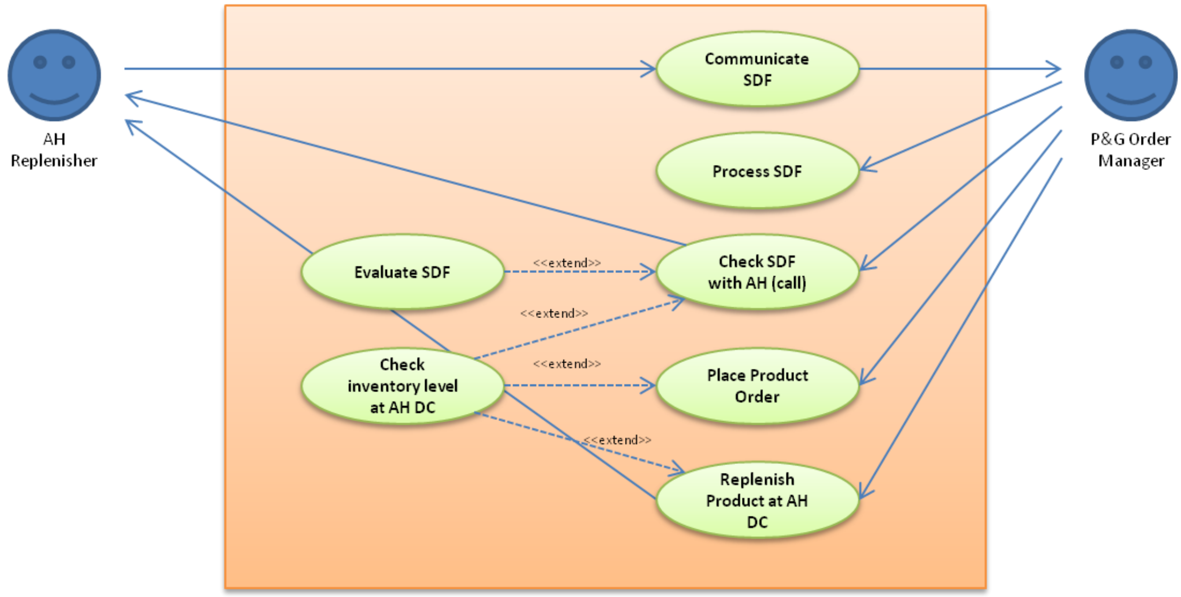

Figure 19: Use-case diagram of Retailer X DC order & replenishment

Procter & Gamble ordering & replenishment

In the ordering and replenishment of products at the DC of Procter & Gamble, various agents have interactions with each other to ensure that orders are being converted into replenishment and production. The whole process is broken down into four use-case diagrams in which the complete "Procter & Gamble order & replenishment" process is shown.

Procter & Gamble Supply Planner

The Procter & Gamble Supply Planner receives a product order of the Procter & Gamble order manager. The Procter & Gamble Supply Planner then receives the order, processes this and places a new supply order. Before the supply order is done, the Supply Planner checks for promotions, the needs from other retailers and the inventory level of the product at the Procter & Gamble DC.

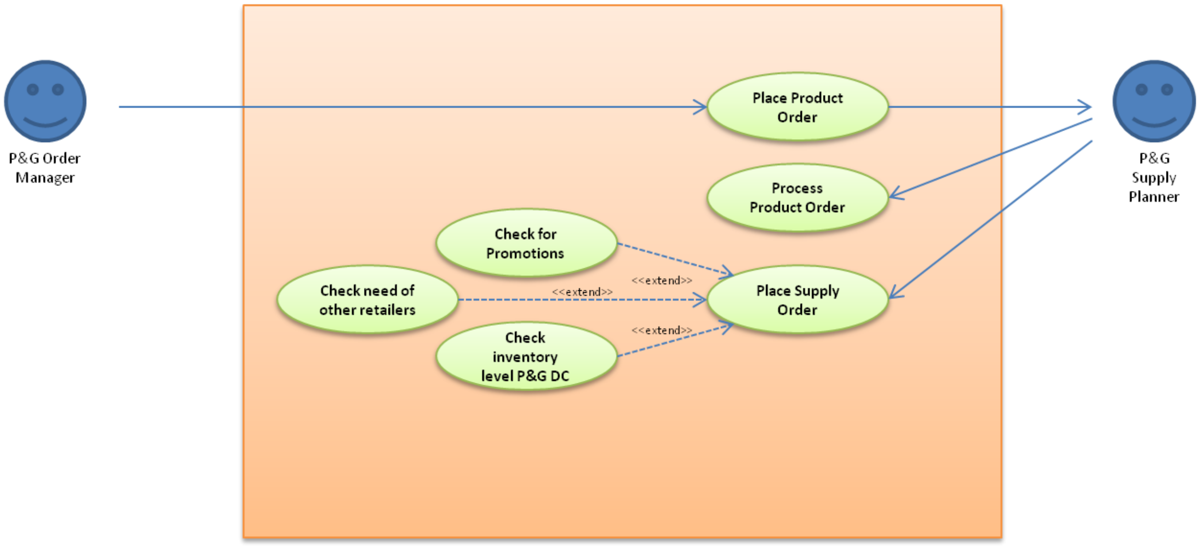

Figure 20: Use-case diagram of Procter & Gamble supply planning

Procter & Gamble Demand Planner

The Demand Planner is responsible for converting the supply order from the Supply Planner into demand orders. This is done by processing the supply order and converting this with the help of long term business intelligence and total market demand into a demand order that is transferred to the plant. The process is shown in the figure below.

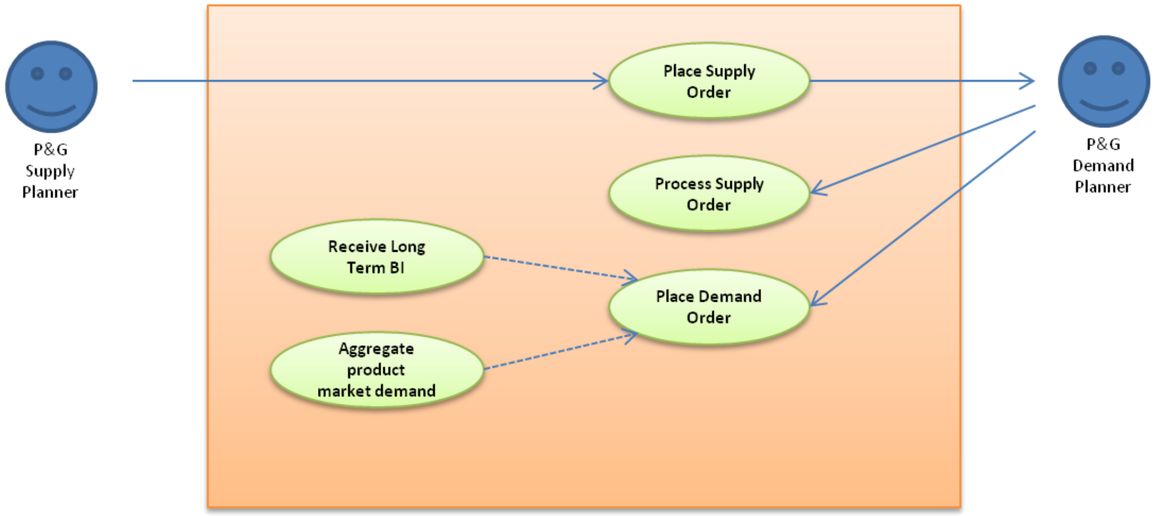

Figure 21: Use-case diagram of Procter & Gamble demand planning

Procter & Gamble Production Planner

The Production Planner is responsible for meeting the demand order. The demand order is the primary input for the Production Planner to trigger production of the product (Dreft ADW). The Production Planner first processes the demand order, than he makes a production planning based on this input and the total aggregated product demand (from other markets) and the raw material inventory. Then a certain amount of product gets manufactured, also based on the raw material inventory and product inventory at the Procter & Gamble DC. This triggers replenishment of the Procter & Gamble DC, which is communicated to all the downstream agents who need information on the inventory levels at the DC of Procter & Gamble (Order Management, Supply Planner and Demand Planner). Furthermore Raw Materials need to be ordered.

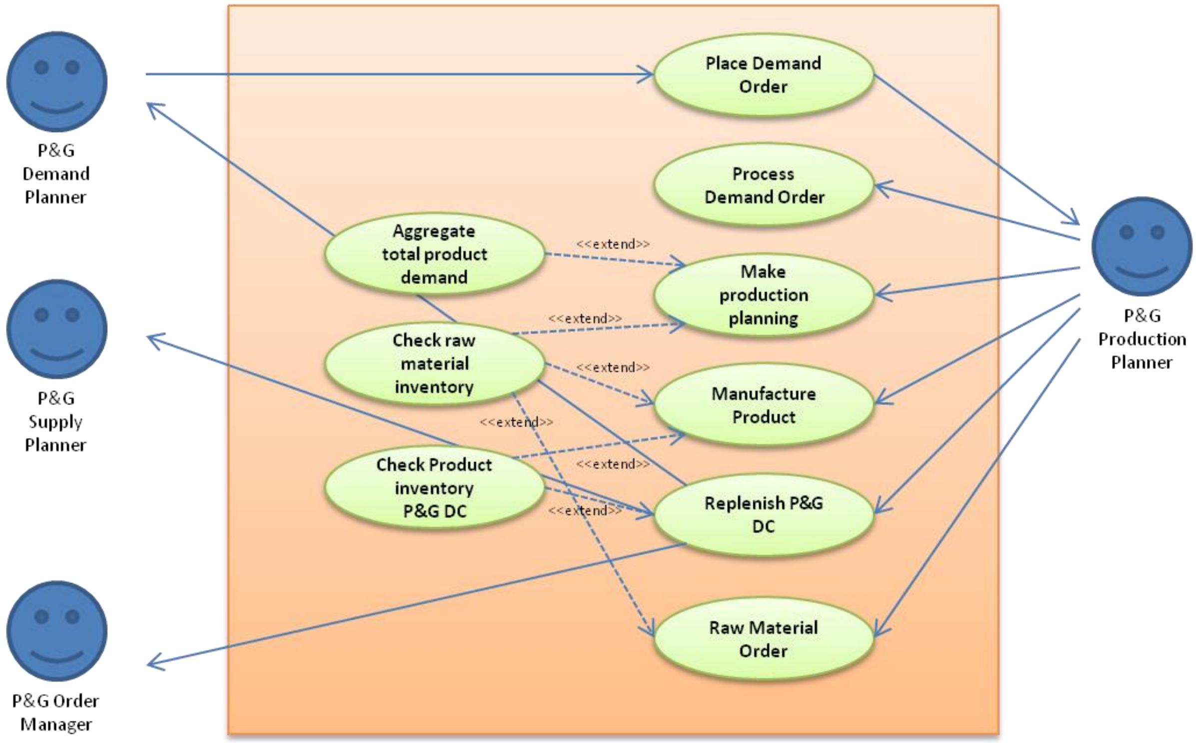

Figure 22: Use-case diagram of Procter & Gamble production planning

Raw Material Supplier

The last agent in the ABM is the Raw Material Supplier. This agent translates a raw material order into replenishment of the raw materials at the Procter & Gamble Production Planner. After the Raw Material Supplier receives a raw material order, it processes the order and replenishes raw materials needed for production. This is communicated to the Procter & Gamble Production Planner.

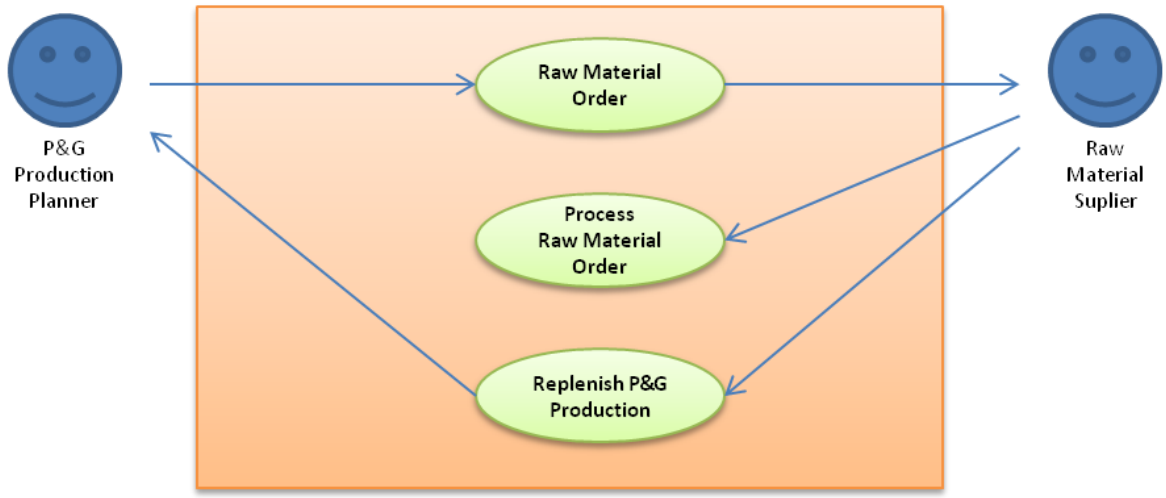

Figure 23: Use-case diagram of raw material supply

7.5. Concept formalization

In the concept formalization step, the modeler is forced to define the different aspects of the model to be able to make it computer-understandable. A computer can calculate rationally on the basis of primary inputs of the modeler. Therefore simplifications need to be made in certain situations; this is also described in this step.

Types of agents

In the previous section we defined six important agents: RETAILER X Replenishment, Procter & Gamble Order Management, Procter & Gamble Supply Planning, Procter & Gamble Demand Planning, Procter & Gamble Production and Raw Material Supply. In this study the Raw Material Supplier is not an entity with its own behavioral rules; it merely is a supplier of goods that are being used in the production of Procter & Gamble.

For the ease of programming, we defined three stakeholders not as agents but as a primary input of information. These three agents are the consumer and the commerce departments of Retailer X and Procter & Gamble. Although these agents have an important role, it is taken that their information output is not a function of the choices they make as an actor.

Ultimately the model thus includes five agents that have behavioral rules and act on and interact with their surroundings.

To describe the order and replenishment processes in the supply chain, use-case diagrams are made for the various agents in the models.

Variables and attributes

In Figure 24 a full overview of all variables and attributes of the agents are given. These variables and attributes were identified in the stakeholder interviews and regarded as useful or required to correctly model the several iteration steps needed to correctly simulate the supply chain of Dreft ADW.

Figure 24: Model elements, attributes and relations

7.6. Model formalization

This section focuses on the actions and interactions between the different elements that were shown in Figure 24. With the help of a data-analysis and stakeholder analysis, we have decomposed our system and established the dynamics that are of interest. With the detailed description on the actions and interactions between the different elements, we will be able to identify what happens to whom if changes in the system occur (either by an agent changing its behavior or changing the environment input).

In this model, there are five agents that actively make decisions. The RETAILER X Replenisher, the Procter & Gamble- Order Manager, Supply Planner, Demand Planner and Production Planner. The time step in the model is hourly based, whereas the period of interest is a year or several years. To be able to build a model that will not take ages to run a “simple” experiment, it is needed to design the logic of the model carefully.

We have set-up a control logic that calls or executes mechanisms only when the time is right; order placements at certain hours of the day, promotional procedures during promotions etcetera. In Figure 25 a full overview of the control logic is given. Later in this section we discuss the mechanisms of each agent at designated time dimensions. With the help of use-case diagrams, the different actions and interactions of the various agents, with respect to the ordering & replenishment processes, are put into (a computer understandable) model sequence.

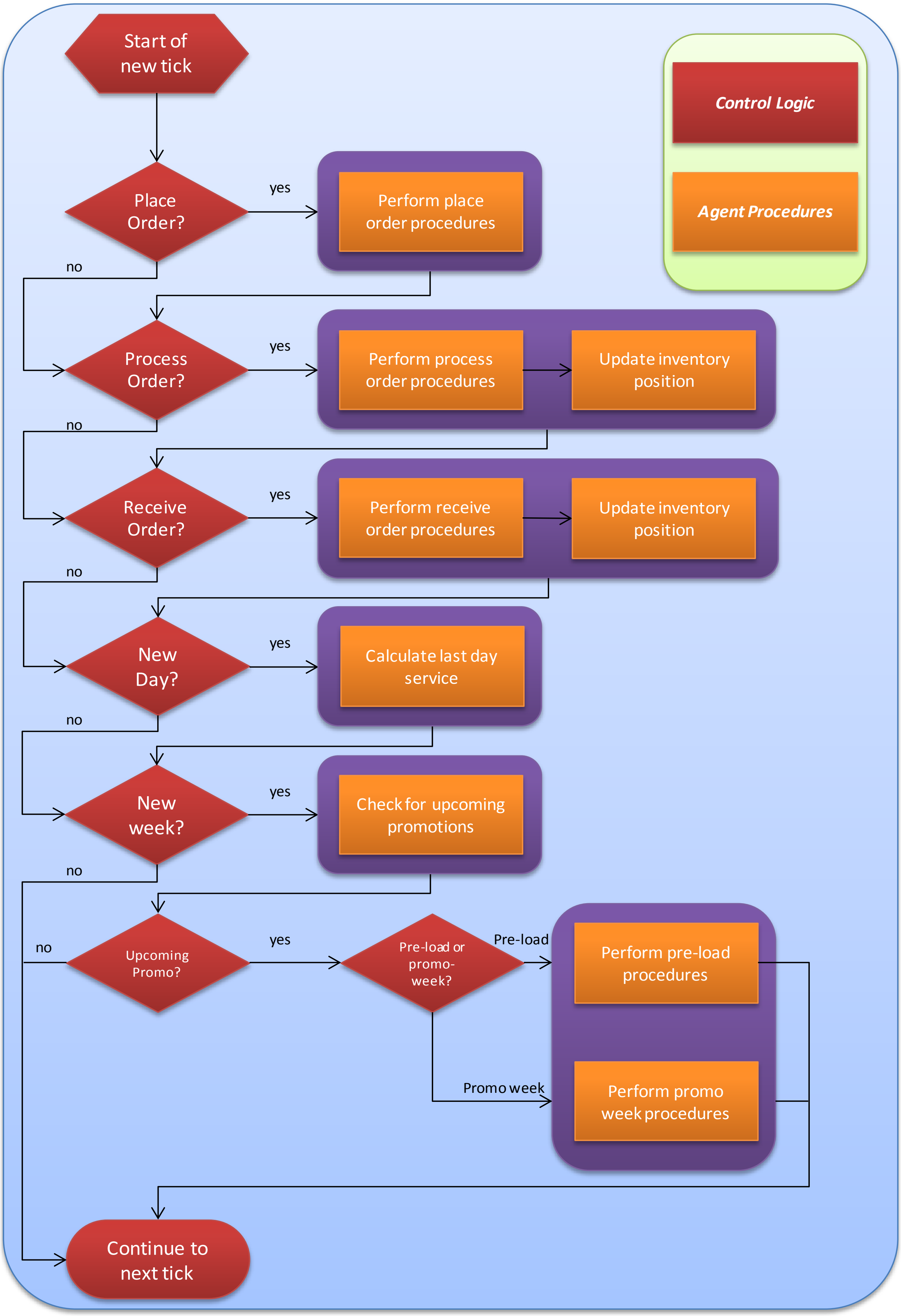

Figure 25: Model sequencing

"Place Order" Procedures

When running the model, the first procedure that will be executed is the ordering of products by the various agents. If the new tick triggers the ordering procedure of an agent, the specific agent will place an order at the next agent in the supply chain.

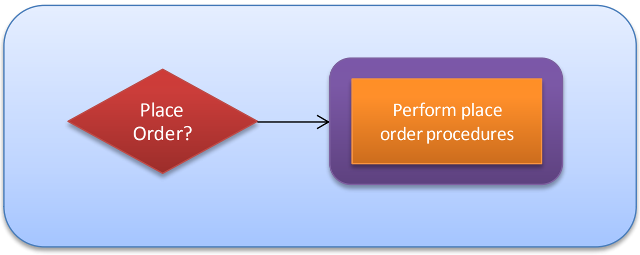

Figure 26: Place order procedures

Agent: Retailer X Replenishment

When this process is triggered, Retailer X Replenishment places an "order" at Procter & Gamble Order Management by providing them a store demand forecast. This is based on a standard safety-factor, current inventory level of all stores combined, the safety-stock policy and a minimum order quantity.

Agent: Procter & Gamble Order Management

By triggering this process, Procter & Gamble Order Management places an order at Procter & Gamble Supply Planning by providing them a total product order needed to replenish the Retailer X DC. This is based on the current inventory level at the Retailer X DC, safety-stock policy and a minimum order quantity.

Agent: Procter & Gamble Supply Planning

Procter & Gamble Supply Planning places an "order" at Procter & Gamble Demand Planning by providing them a total expected product supply demand needed to replenish the Procter & Gamble DC. This is based on the current inventory level at the Procter & Gamble DC, safety-stock policy and a minimum order quantity.

Agent: Procter & Gamble Demand Planning

Procter & Gamble Demand Planning places a final "order" at Procter & Gamble Production Planning by providing them a total production need of the specific SKU. This is based on the current inventory level at the Procter & Gamble DC and a safety factor.

Agent: Procter & Gamble Production Planning

The last order placement in the model is by the Production planning of Procter & Gamble. Production Planning places a raw-material order at the Raw Material Supplier by providing them a raw-material order. This is based on the current raw material inventory level at the manufacturing plant, safety-stock policy and a safety factor.

"Process Order" Procedures

The second step in the sequence of the model is whether or not an order needs to be processed by a certain agent. Thus if a tick happens to trigger the procedure of processing an order, the specific agent will perform the actions that are needed to process an order.

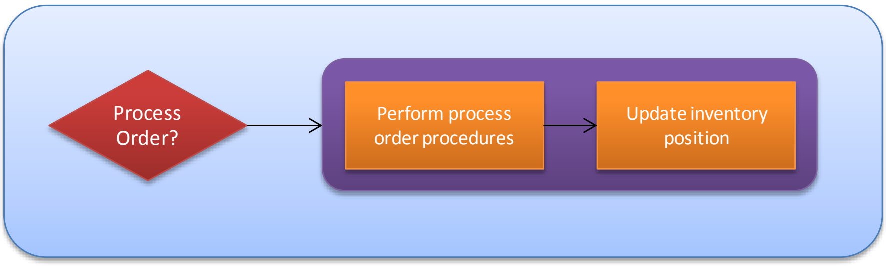

Figure 27: Process order procedures

Agent: Retailer X Replenishment

When this process is triggered, Retailer X Replenishment processes last day's sales. The "filled-orders" (the sales of last day) are used to update the inventory-position to create an up-to-date (current) inventory level that will be used to determine the amount of products that need to be ordered. Missed-sales are recorded in a cumulative manner over the duration of the experiment.

Agent: Procter & Gamble Order Management

This process is triggered when an order is placed by Retailer X replenishment. Order Management of Procter & Gamble receives a store demand forecast from Retailer X replenishment. This is used to update the current inventory position, the inventory position when the store demand forecast will be shipped from the Retailer X DC to the stores. Although in real-life this inventory update really happens when orders are picked (at 3 PM), for the ease of modeling this is held at 10 AM. This does not influence the outcome of the model as replenishment of the DC still occurs at a later time. The missed cases are recorded and put in the system as backlog.

Agent: Procter & Gamble Supply Planning

If an order is placed by Order Management, the Supply Planning of Procter & Gamble receives this product order for the Retailer X DC. Just as Order Management, they update the inventory position at the Procter & Gamble DC and record missed cases as backlog to be sent when inventory is available at the Procter & Gamble DC.

Agent: Procter & Gamble Demand Planning

The Demand Planning of Procter & Gamble receives the supply demand for the Procter & Gamble DC of a specific SKU and processes this information, when an order is placed by Supply Planning. The information is not changed in this step, but is needed to keep the model sequence flowing.

Agent: Procter & Gamble Production Planning

After the Demand Planner places their order, the Production Planning processes the production need. Production is triggered with a minimum production batch size (thereby fulfilling the order of Demand Planning) and raw-material inventory at the plant is updated. Potential misses are recorded as backlog.

Agent: Raw Material Supplier

At 4 PM, the Raw Material Supplier processes the raw-material order (if there is any) and fills the order of the Production Planner of Procter & Gamble.

"Receive Order" Procedures

When orders are placed and processed, the next step in the modeling sequence is to check whether or not an order will be received by one of the agents. If this happens, the "receive order" procedures will be put in place.

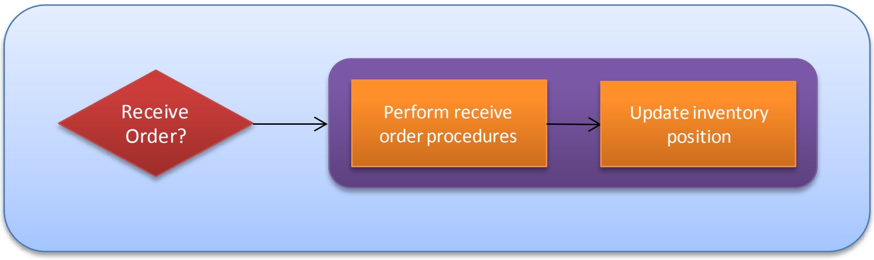

Figure 28: Receive order procedures

Agent: Retailer X Replenishment

Once the placed order of Retailer X replenishment is processed by Procter & Gamble Order Management, Retailer X Replenishment "receives" this order after a lead-time of X hours after the placement of the order. Thus X hours after an order is placed the amount that is processed by Procter & Gamble Order Management is received by Retailer X Replenishment. The inventory position of the Retailer X stores is subsequently updated with the received amount of products.

Agent: Procter & Gamble Order Management

Procter & Gamble Order Management receives their order X after their order is placed at the Procter & Gamble Supply Planning (if this department is able to process the order). Inventory at the Retailer X DC is updated with what is sent by Procter & Gamble Supply planning.

Agent: Procter & Gamble Supply Planning

The same "order receive" procedure is in place for the Supply Planning of Procter & Gamble. After this department places their order, the order is received X hours later in the DC of Procter & Gamble (lead-time of ordering, manufacturing and transporting the product). The inventory level is then updated with the amount of product that is produced by the manufacturing plant.

Agent: Procter & Gamble Demand Planning

Although Procter & Gamble Demand Planning does not actually receive orders (as the agent does not manage actual inventory), for the flow of the model a virtual stock is assigned to Procter & Gamble Demand Planning. In this way the model is able to create the same flow of information and products as for the other agents. Procter & Gamble Demand Planning immediately "receives" their order after this is processed and sent by Production Planning, after which the virtual inventory is updated in the model. This virtual inventory is subsequently used to replenish the inventory level at the actual Procter & Gamble DC.

Agent: Procter & Gamble Production Planning

Procter & Gamble Production Planning receives their raw material order 2 weeks after their order is placed. Raw material inventory position is subsequently updated by the received amount.

"New Day" Procedures

Next to the procedures of ordering and replenishment, there are other procedures that are triggered whenever a new day or new week begins.

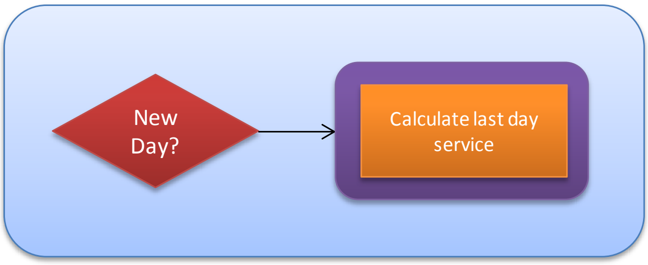

Figure 29: New day procedures

Agent: Retailer X Replenishment

Each day, the amount of missed sales is calculated for the Retailer X stores. This service level is logged as the amount of missed sales. This service level is cumulatively calculated by:

$$Service\ level\ (\%) = \frac{\sum missed\ sales}{\sum sales}$$

Agent: Procter & Gamble Order Management

The service level that is measured each day at Procter & Gamble Order Management is the infamous SAMBC. This measure of service is calculated by the following formula:

$$SAMBC\ (\%) = \frac{\sum missed\ cases}{\sum shipped\ cases}$$

This is the official measure of the service in the supply chain of Dreft ADW.

"New Week" Procedures

Just as there are procedures that are put into working when a new day is triggered, the same holds for when a new week is triggered.

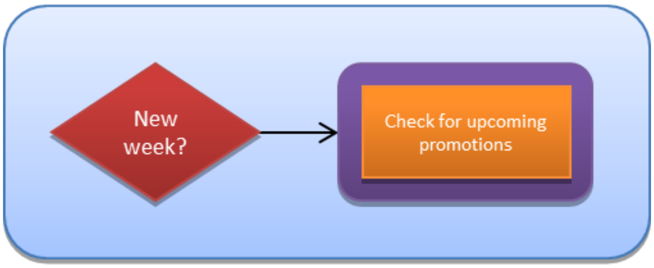

Figure 30: New week procedures

All Agents

Whenever a new week starts, all agents check whether or not in the upcoming weeks a promotion is scheduled. It depends on the agent how far ahead one looks in the future (the upcoming week, 1 week in advance or even possibly 2 weeks in advance). Some agents will need to perform a preloading or even pre-production two week before a promotion, while others only behave differently during the promotion itself. The agents ask this information from the promotion-schedule that is available to everyone.

"Promotional" Procedures

The last step in the modeling sequence comes in place whenever a promotion is coming up. In the previous step the agents check for an upcoming promotion, if this is the case the next step is whether pre-load procedures or promotion week procedures have to be executed.

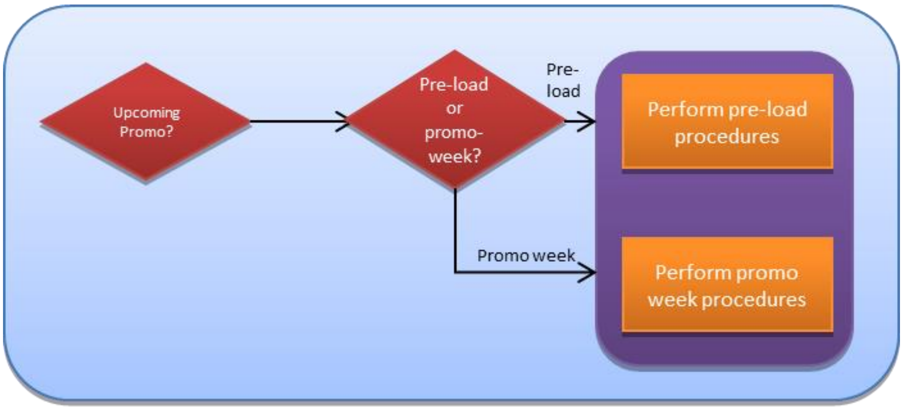

Figure 31: Promotion procedures

Pre-load procedures

This section describes the pre-load procedures of the various agents.

Agent: Retailer X Replenishment

The week before a promotion, the pre-load procedure is triggered to replenish the stores of Retailer X. As described in the stakeholder interviews, the weekend before a promotion, a pre-load of promotional products takes place. Sixty percent of the total forecasted promotional volume is pushed to the stores by on Saturday and Sunday before a promotion. This is done in the model by (stepwise) increasing the safety-stock of the stores to X% of the expected promotional sales, the Sunday before a promotional week.

Agent: Procter & Gamble Order Management

To be able to replenish the stores with the pre-load that is sent the weekend before a promotion, Order Management of Procter & Gamble pre-loads these products from Thursday to Sunday (a total of X%). In the ABM this is programmed in the same way as for Retailer X Replenishment; changing safety-stock policy by increasing the safety-stock of the Retailer X DC the weekend before a promotion.

Agent: Procter & Gamble Supply Planning

Also Procter & Gamble Supply Planning needs to react on the pre-load of the retailer stores. Therefore Supply Planning needs to make sure that there are enough products in the Procter & Gamble DC the week before a promotion.

As the model is programmed as a pull supply chain (replenishment is triggered by sales, not pushed by the factory), we have to artificially model the way the pre-load of the Procter & Gamble DC happens. In real-life a production push happens two week before a promotion, when the manufacturing plant begins producing the first promotion designated products. As this cannot easily be programmed in the chosen way of modeling, we assume that the pre-production is triggered by an order of Supply Planning.

Therefore on Wednesday two weeks before a promotion, X% of the promotional volume is "ordered" by Supply Planning. One week before the same promotion on Tuesday, another X% of the promotional volume is produced (/ordered). This would ensure that the pre-load to the DC of Retailer X (and subsequently to the stores of Retailer X) can be done. These volumes are based on interviews and data-analysis.

Agent: Procter & Gamble Production Planning

Because pre-production is programmed as a pre-load order by Supply Planning, no specific procedures are in place for Procter & Gamble Production Planning in the model.

Promotional week procedures

During the promotional week itself, there are also specific procedures in place for the first two agents in the model of the supply chain.

Agent: Retailer X Replenishment

During a promotional week several changes in behavior are modeled. The following steps in inventory policy are taken by the agent and are based on the actor interviews:

- Whenever a promotional week starts (Monday), the safety-stock will be reset to a promotional safety-stock that can cover the expected (increased) sales demand.
- On that same Monday, Retailer X Replenishment calculates the uplift in sales with respect to the forecast.
- On Tuesday, 25% of the updated total expected sales for the rest of the week is pushed to the stores to maintain full shelves (create a good store-image).
- Throughout the rest of the promotional week, the remaining expected demand is shipped to the stores. This would ensure that the inventory level of the stores is at the safety-stock level at the end of the last day of the promotion.
- On the last day of the promotional week, the safety-stock is reset to the regular sales level (as enough products are shipped the day before to cover the total sales).

Agent: Procter & Gamble Order Management

Although not so extensive as the procedures that Retailer X Replenishment has during a promotional week, Procter & Gamble Order Management has a different ordering and shipping procedure.

- On Monday, the safety-stock is reset to the standard safety-stock plus the expected daily sales.
- When the uplift is known on Tuesday, the safety-stock is reset to standard safety-stock plus updated expected sales.
- On Sunday, the promotional safety-stock is reset to the regular safety-stock.

Whenever a promotion comes to an end, all different procedures build into the model have passed the revue and the model can proceed to a new tick. This process is repeated until the end of an experiment. To be able to program the supply chain in a computer model and subsequently run it with easy, assumptions need to be made to filter out irrelevant behavior and still closely resemble reality. This list of assumptions is given in the next section.

Overview of used assumptions

At this point in time, we know how to describe the relevant behavior and dynamics of the agents in the model. Several assumptions are made to run the model fluently, while maintaining a close similarity to reality. Below a list is given of all the assumptions that are made in the model.

Consumer Demand Assumptions:

- Products are sold 7 days a week and sales are evenly distributed throughout the week.
- Regular (non-promo) sales are expected to be constant over a year *or* have <u>one</u> sudden increase after which sales stay constant at that level.

- Regular sales fluctuate daily with a standard deviation of 25% of the (constant) regular sales number.
- Promotional sales are evenly distributed throughout the promotional week.
- Promotional sales are taken from historical data.
- Promotional forecasts are taken from historical data.
- Hourly sales/sales peaks are assumed to be irrelevant as sales are extracted for order preparation once a day.

Place Order Assumptions:

- Orders can be placed every day at a designated time (dependent on the specific experiment); these replenishment opportunities are available in real-life.
- Store demand forecast is generated by multiplying last day sales with a safety factor of 1.2.
- Mimimum order quantities (1 case, 1 pallet, 1 production batch) are based on historical data and interviews and do not change over the time of an experiment.
- Minimum order quantities are always respected by all agents.
- Regular safety-stocks are constant over the year, unless there is a sudden increase in regular sales (see consumer demand assumptions), then safety-stock is re-evaluated. Safety-stocks are based on historical data.
- The safety factor taken on Procter & Gamble DC inventory is 1.2 and factored in by Procter & Gamble Demand Planning.
- No human errors are taken into account in placing the order.

Process Order Assumptions:

- Orders are processed immediately (the same “tick”) after an order is placed by the agent downstream in the supply chain.
- When an order is processed, the inventory position is updated by subtracting the ordered amount from the last know up-to-date (current) inventory level.
- When a warehouse is out of stock, missed shipments are recorded, backlogged and added up to next-day’s order.
- It is assumed that whenever the stores go out of stock, the sales are lost and the consumer buys another product (no backlog on these products).
- A virtual product stock is assigned to the agent Procter & Gamble Demand Planning for the ease of modeling.
- Products can be produced every day.
- Stock of the Raw Material Supplier is taken to be constant and can always meet demand.
- No human errors are taken into account in processing the orders.

Receive Order Assumptions:

- Lead times are X hours, X, X hours and X weeks respectively when walking back the supply chain (Retailer X stores to Raw Material Supplier)
- Order picking, unloading & loading of trucks and transportation are assumed to be included in the lead-time.
- We assume that there are no delays in lead-time.
- Inventory is always updated with the filled orders by the agent upstream in the supply chain.
- For the ease of modeling, we assume that the agent Procter & Gamble Demand Planning has an own virtual stock.

- During shipments, we assume that no products are damaged or lost.
- No human errors are taken into account in receiving the orders.

New day assumptions

- Service level is only calculated for the first two agents.
- The amount of total missed cases is the sum of the total backlogged cases.

New week assumptions

- Checking of promotions is done from a predetermined schedule.
- Promotion schedule for the complete fiscal year is assumed to be known at the beginning of the experiment, taken from historical data.
- Surprise, last-minute, promotions do not exist, because promotion procedure timings all fall within the contractually agreed upon 4 week notice of a promotion. Therefore the outcome of the model would not be influenced if there are new promotions planned 4 weeks ahead. Therefore for the ease of programming a predetermined promotion schedule is used.

Pre-load assumptions

- X% of the forecasted promotional volume is pre-loaded in the stores in the weekend before a promotion.
- X% of the forecasted promotional volume is pre-loaded in the Retailer X DC on the Thursday before a promotion.
- X% of the forecasted promotional volume is pre-loaded in the Procter & Gamble DC in the two weeks before a promotion.
- In real life, the pre-loading of the Procter & Gamble DC occurs through a production push, but for the ease of modeling we have made an artificial push by programming forced pre-determined product orders by Procter & Gamble Supply Planning.

Promotion week assumptions

- Promotional safety-stocks of the agents are assumed to be the regular safety-stocks plus the expected daily sales during a promotion.
- Uplift is calculated each Monday by dividing the actual Monday sales through the forecasted sales.
- 25% of the remaining expected sales are pushed to the stores on Tuesday during a promotional week.
- At the end of Sunday at the promotional week, safety-stocks in the various parts in the chain are being reset to the regular safety-stocks taken from historical data.

7.7. Software implementation

The computer model has been made in the program NetLogo 5.2.0 and data processing was done in Microsoft Office Excel 2010. The programming software NetLogo 5.2.0 was used because it has a low entry barrier; the coding is easily understood and functions dictionary is detailed and extensive. The model was build according to the description of the formalized model in the previous sections.

7.8. Model Interface Build-up

On the next page you will find a print-screen of the NetLogo interface with in it numbered variables. These variables will be explained in short below. With this model, validation runs are done with historical data.

1. This is a visualization of the agents that are in play, utmost left; Retailer X Replenisher and at the right hand the Raw Material Supplier
2. These are the initialization buttons. Setup makes sure that the right initial values are being used before an experiment, Go Once lets the model run 1 tick (in this model 1 hour) and Go lets the model run until the end of the experiment.
3. These are monitors of different values. When the model is running, at the left there are four inventory plots shown. At the right, values on service, sales etc. are shown.
4. These are input parameters that have an influence on the whole experiment. For example, running the model with historical real-life data, or actually running experiments with improved visibility, transparency and interconnectivity (the scenarios defined in the workshop with Procter & Gamble and RETAILER X).
5. These are input parameters that are related to runs with real-life data. For example, the amount of years that we want to run the experiment.
6. These are input parameters that are dedicated to a single agent and can vary per SKU of Dreft. Initial safety-stocks and inventories; are especially important when running with historical data.
7. These are parameters that are also specific for a single agent, but are (in real-life) restricted to external forces; lead-times cannot easily be changed and a MOQ is often decided upon by higher management.

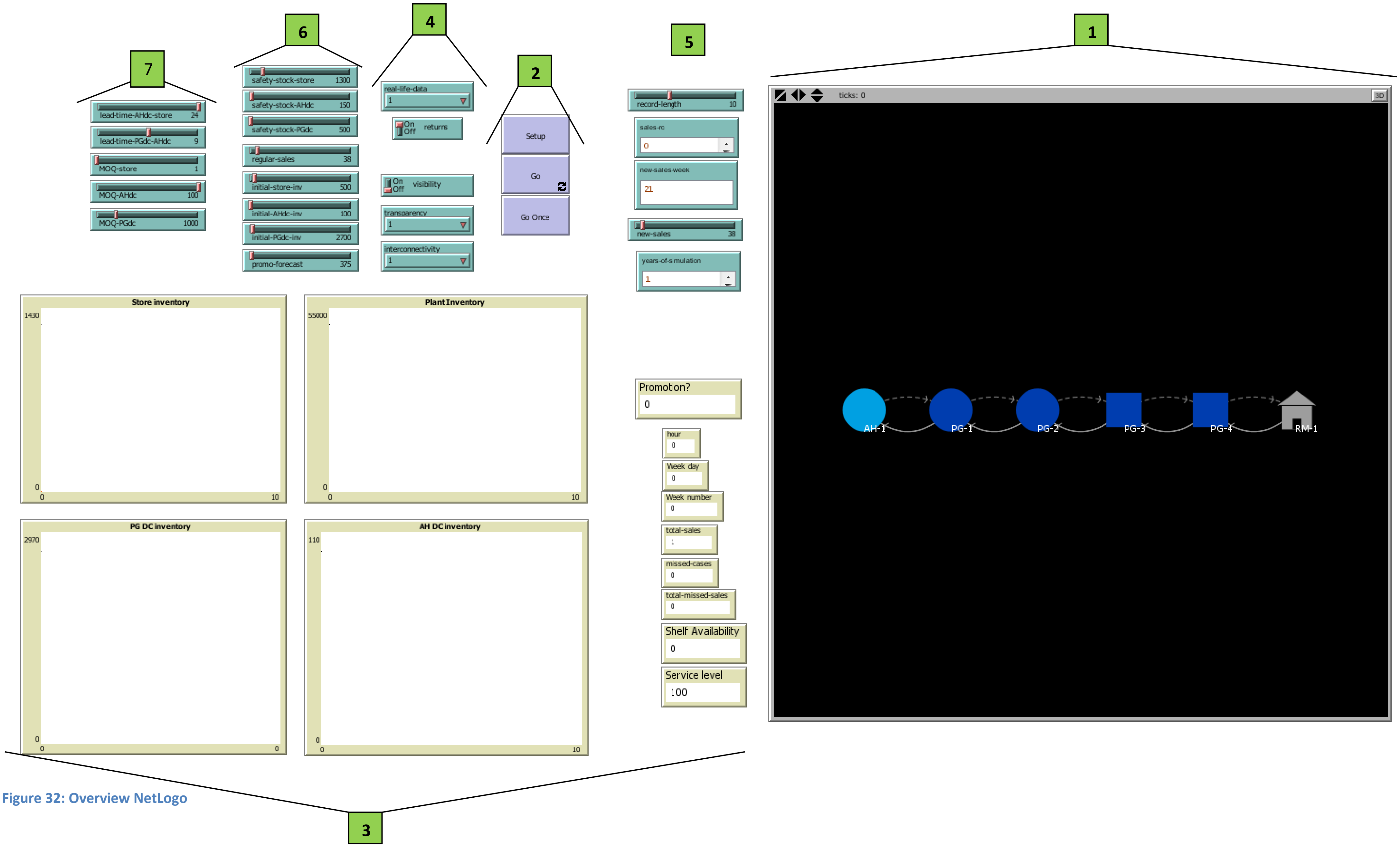

Figure 32: Overview NetLogo

7.9. Experimentation Approach

This section describes the initial choices that need to be made to run the model accurately. What data-set needs to be used as input, how to set up the control variables, environmental variables and what the initial choices will be for execution of the model.

Data input choice

All experiments were done on predetermined set of SKUs separately and then the data of the various experiments was aggregated. The set of SKUs needed to satisfy the following boundary conditions:

- The percentage share of RETAILER X on the SKU should be larger than 50%. Thus of all shipments from the Procter & Gamble DC to all retailers, more than 50% of the volume needed to be shipped to Retailer X. Meeting this condition would ensure that the choices made in the model would represent reality as the shipments to Retailer X would in real-life also be most likely the ones that would trigger production.
- The total shipment size of the SKU to Retailer X should be significant with respect to the total amount of shipments of Deft ADW to Retailer X. Although weighted averages were taken (making this boundary conditions less important), it was chosen to take this into account to reduce run time of the model and subsequent time spent on the data-analysis.
- A steady flow of Dreft ADW throughout the year was mandatory. In the analysis we discard promotional SKUs, or SKUs that have been phased out throughout last fiscal year.

These three boundary conditions narrowed down the data-set of SKUs that were suitable for experimentation with the model. In total only three SKUs did meet the set of boundary conditions. The three SKUs that met the boundary conditions are mentioned below

Table 7: Overview of in modeling scope SKUs

Together these three SKUs account for (X / 10000000 =) X% of the total volume of Dreft ADW shipped to Retailer X and can therefore be taken as a representative data set to be able to generalize the results of the model for large regular selling volumes.

Control variable choices

All experiments were done for three different SKUs, of which the outcomes were aggregated and/or weighted average values were taken. For each SKU a "re-run" of last fiscal year was done, where each experiment represents a scenario where a certain degree of vertical collaboration is simulated (based on the in chapter three defined Supply Chain interventions). To be able to run the experiments, some initial control variables choices needed to be made.

Production batch size

One of the variables that could be controlled was the minimum production batch size of the manufacturing plant. Four separate production batch sizes were chosen to simulate.

- 2000 cases of the respective SKU (current day batch size)
- 1000 cases of the respective SKU

- 500 cases of the respective SKU
- 100 cases of the respective SKU

Vertical collaboration

The suggested interventions for the supply chain of Dreft ADW based on vertical collaboration and information sharing were:

- Visibility
  - No change with current real-life data sharing process (0)
  - Sharing of POS data (+)
- Connectivity
  - No change in current real-life information process (0)
  - Information order release process alignment during promotions only with a Monday afternoon order release (+)
  - Full information order release process alignment; afternoon release and nighttime delivery (++)
- Transparency
  - No change in use of available information with respect to current situation (0)
  - Use of up-to-date available data in production planning (+)

All the different combinations of the above named interventions yield the following experiments:

Table 8: Experiment overview

	Visibility	Connectivity	Transparency
Experiment 1 – base experiment	0	0	0
Experiment 2	+	0	0
Experiment 3	0	+	0
Experiment 4	+	+	0
Experiment 5	0	++	0
Experiment 6	+	++	0
Experiment 7	0	0	+
Experiment 8	+	0	+
Experiment 9	0	+	+
Experiment 10	+	+	+
Experiment 11	0	++	+
Experiment 12	+	++	+

Environmental variables

This section discusses (in short) the input for the environmental variables. Settings were based as much as possible on credible sources.

Experiment run-time: 1 year

As Procter & Gamble would like to simulate the full past fiscal year, the run-time of the simulations was limited to one year per run.

Delivery lead-time: variable

The initial input choices for the delivery lead-times between the various points in the supply chain are listed below.

- *Raw-Material to Plant: X weeks*

  The time it takes for the raw-materials to reach the production plant is taken to be X weeks. In real-life this varies strongly per raw-material supplier and raw-material. This is however not really important as the safety-stock of this material is taken to be more than enough to not run out of raw-materials
- *Plant to Procter & Gamble DC: X hours*

  In interviews with the "flow-manager" of the manufacturing plant of Procter & Gamble it became clear that it took X hours to place an order, process the order, plan the production, produce the product and then transport it to the DC of Procter & Gamble.
- *Procter & Gamble DC to Retailer X DC: X*

  Contractually Procter & Gamble and Retailer X have agreed that X after Retailer X places an order, Procter & Gamble needs to have their product delivered at the DC of Retailer X.
- *Retailer X DC to Store: X hours*

  In interviews with the "flow-manager" of Retailer X, it turned out that it took X hours after a store order was placed at the Retailer X DC to arrive at the store. We take in this case the longest lead-time as a shorter lead-time would only yield better results.

Regular store sales: variable per SKU

Store sales were randomly generated around an average based on historical data.

Promotional store sales: variable per SKU and promotional week

The input for the sales during promotion weeks was taken from historical data.

Promotional forecast: variable per SKU and promotional week

Just as for the sales during a promotion week, the forecast was taken from historical data obtained from the data center of Procter & Gamble.

Promotional pre-load: 60% of initial promotional forecast

Based on interviews with the relevant stakeholders, the initial pre-load of promotional volume to both the DC of Retailer X and the stores is taken to be 60%.

Minimum Order Quantities (MOQ): variable per agent

Dependent on the section of the supply chain, the minimum order quantity varied per agent.

- *MOQ of store orders: 1 case*

  The MOQ of the store orders is 1 case (based on interviews/field research/historical data)
- *MOQ of RETAILER X DC orders: 1 pallet (100 cases)*

  According to interviews with the relevant people, it turned out that in general, the MOQ for orders designated for the Retailer X DC is 1 pallet. In exceptional cases less than a pallet is shipped, for simplicity this is left out of the modeling.

Safety-stock: variable per SKU and agent

Safety-stocks are taken from historical data and actor interviews. The safety-stocks vary per agent (storage point in the supply chain) and per SKU.

- *Safety-stock at the store: 1400 cases*

  A single store places a new order if their store inventory drops below 1.5 cases. With approximately 950 stores, this comes down to an aggregated "safety-stock" of 1400 cases.
- *Safety-stock at the RETAILER X DC: 1/2 week of inventory*

  As the VMI contract between Retailer X and Procter & Gamble states that the inventory level at the Retailer X DC should be maximum 1 week of inventory. This means that if the inventory drops below the point where it is expected that it would cover 1 week of sales, a new order is placed.

- *Safety-stock at Procter & Gamble DC: varied per SKU based on historical data*
  The safety-stocks that were used in the FY 14/15 according to the retrieved historical data served as input for the model.

Initial inventory level: variable per SKU and agent

The inventory levels according to the historical data at the beginning of the FY 14/15 were used as input.

Execution of the model

Although execution of the model is not highly computational intensive, calculations are done on an hourly basis in which a large part of the time almost nothing computational intensive happens. However some initial choices were made before executing the model:

- Model run-time was limited to 1 year, as (an improved) history of FY 14/15 was simulated.
- Each single experiment was run 20 times to create a data-set that would average out the outliers in certain experiments.
- KPIs were logged throughout the experiment at each "tick".

The KPIs that were logged were:

- Service as measured by the customer
- Inventory at the Store, Retailer X DC and Procter & Gamble DC

In total per SKU per batch size 240 runs needed to be simulated, so a total of 2880 runs were simulated. The time for a single run took approximately 10 seconds. Simulations were done on a dual core processor allowing 2 runs at a time.

7.10. Model verification and validation

Although the approach by van Dam et al. (2013) uncouples validation and verification and places model validation after experimentation with the model, it was chosen to deviate from his method in a small way. The validation and verification steps were perform simultaneously before starting the designed experiments.

The choice to deviate from the 10 step approach was because of the different interests of the problem owner and the scientific community and timeline of the project. Procter & Gamble, the actor who issued the project, was mainly interested in short-term easy supply chain changes that could improve their KPIs when the environment would not change; e.g. running experiments with historical data to identify what the KPIs would have been had the changes been in place. However the scientific community (personified by the Delft University of Technology) would be more interested in the findings of changes in long-term scenarios. It was therefore chosen to build a model, perform the verification and validation steps and then enter the experimentation phase.

7.11. Verification

Model verification is done to check whether the conceptual model is correctly translated into a computer program. Model verification steps are carried out to identify possible mismatches between our intentions with the model and efforts of the modeling. We have followed the model verification steps of Van Dam et al. (2013). The follow tests have been executed in the process:

- Recording and tracing Agent behavior
- Minimal Model testing: Sanity Checks

- Full model observation

We have performed the above set of tests and at this point in time we have fixed all problems that have occurred during several tests and preliminary runs and we can confirm that the flaws in the model have been fixed and the model is verified.

7.12. Validation

Validation of the model has the primary goal to identify whether or not the model is a tool to rightfully and correctly answer the main research question. If one is not able to answer the main research question with the help of the designed computer model, the model is not necessarily wrong, but it is useless for this research. Validating the model before running the experiments was done to not lose time by running experiments on a model that is flawed in its core and would therefore yield faulty conclusions.

When we are validating the model, we are focusing on two kinds of validity that both need to be evaluated:

1. Internal validity: properly demonstrating that there is causal relation between two variables in the model (Creswell, 2013).
2. External validity: the extent to which the causal relations within the model can be extrapolated and generalized to other situations (and in this case: supply chains, goods, companies etc.) (Creswell, 2013).

Four different kinds of model validation methods are mentioned by van Dam et al. (2013) in his approach for building and using an ABM:

- Model replication
- Historic replay
- Literature validation
- Face validation through expert consultations

It would be very interesting if all four methods could be used in validating the model of this research project, this was however not possible for this model.

Model replication is a method that would be very useful and very strong in validating the model, this is however also very time consuming and labor intensive. Model replication requires the modeler to find another model that describes the same system, which often results in finding another person to construct a model of the same system. This would allow a test to find out whether the model assumptions and relevant deemed processes are actually valid. If a second model would yield the same results, both models and their specifications could be considered valid. In this research it was chosen not to do this method of validation, as there were no models available of the same system and no one would be able to replicate the model as the model uses also confidential information. That would not be available to people outside of the company Procter & Gamble (this does say something about the external validity of course).

The second method of historic replay is actually what Procter & Gamble is mostly interested in. Therefore it was chosen to use this method to validate the model. Based on the available data on the KPIs, obtained from the various stakeholders/agents in the supply chain, we will reflect the outcomes of the model to the historical data. There are some limitations to using this method, which will all be discussed.

Literature validation is a method that has similarities to validation by historic replay. It was chosen not to focus too much on this method of validation. The main problem that would arise with using this method is the fact that literature on vertical collaboration in the supply chain is available on a top level, but what we are interested in is the quantitative effects of implementing this into a supply chain. Apart from the fact that there is only limited research done on these quantitative effects, this research is quite case-specific and validating the results with other case-studies might not be representative.

The last method of validation is by consulting experts with knowledge of the system. This is a very valuable method when validating case-studies. Experts within Procter & Gamble and Retailer X know how all processes elapse within the actor and within the supply chain. Therefore the validation of this model will also be done by expert consultation on the face validity.

Validation through historical replay

This method of validation uses historical data to validate the outcomes of the model. If one wants to validate their model with this method, one is heavily dependent on the availability of historical data. Luckily, the most important stakeholders in the chain (Retailer X and Procter & Gamble) supported the project and were very open in sharing their historical data. Therefore, the data (related to Dreft ADW) that was available for data-analysis, model building and historical replay was:

- Store Sales Data
- Promotional Forecast Data
- Service As Measured by the Customer (SAMBC) Data
- *Shelf Availability Data*
- *Store Inventory Data (single measure of current store inventory)*
- Retailer X DC Inventory Data
- *Retailer X DC to Retailer X Store Shipment Data*
- Procter & Gamble DC Inventory Data
- *Procter & Gamble DC to Retailer X DC Shipment Data*
- *Procter & Gamble Manufacturing Plant Production Data*

The underlined data points were used as measures for the validity of the model. This had a few reasons:

- Store Sales Data & Promotional Forecast Data: As the famous quote Garbage IN = Garbage OUT says, when the historical store sales data does not match with the input of the model, the output can never be right. Therefore this is one of the important measures for the validity of the model. As a large part of the misses occur due to forecasting errors, the promotional forecast data was used as an input for the model for the forecasting of the promotion weeks in the historical replay, while the actual promotional sales were used as input for the store sales.
- Service As Measured by the Customer (SAMBC): As SAMBC is one of the KPIs it is of vital importance that this is measured correctly and that the model correctly predicts the SAMBC. If the SAMBC coincides with the historical data, a real estimation can be made of the impact of high collaboration on this KPI.
- Retailer X DC Inventory Data: This is an important measure, as it provides insight in the inventory practices at the Retailer X DC. If the historical data coincides with the model data, it is a validation of the replenishment process for the Retailer X DC and the validity of the ordering process at the Retailer X DC. Furthermore inventory in the chain is a KPI and therefore a good validation if the levels coincide.
- Procter & Gamble DC Inventory Data: Just as for the Retailer X DC Inventory Data, the historical inventory levels of the Procter & Gamble DC can be used to validate the processes of replenishment of and ordering at the Procter & Gamble DC in the model.

Next to the underlined data there are *italic data points*. These are data points that are recorded in the model and where certain decisions and restrictions of the model are based upon.

- Shelf Availability Data & Store Inventory Data: Shelf availability data is a measure of which the historical data is not accurate. It is measured as the percentage of time that a shelf is not empty. In the model this cannot be measured, as it measures total sales that are missed due to out-of-stocks at the store and not the percentage of time that a shelf is supposedly empty (as “shelves” do not exist in the model). The historical data on store inventory was not available for the complete FY 14/15 and therefore the inventory data that comes out of the model cannot be checked. These two measures combined give an indication of the processes of replenishing the consumer and whether these can be regarded as correct with the model.
- Retailer X DC to Retailer X Store Shipment Data: This was used to determine the minimum order quantities that the orders should have. The minimum order quantity that the historical data showed was 1 case.
- Procter & Gamble DC to Retailer X DC Shipment Data: This data showed that the minimum order quantity for replenishment of the Retailer X DC is 1 pallet of Dreft cases; 100 cases.
- Procter & Gamble Manufacturing Plant Production Data: Because Dreft ADW gets shuttled immediately after production to the Procter & Gamble DC, the production data showed the “minimum order quantity” of replenishment of the Procter & Gamble DC because this is limited to the minimum Production Batch size. The data showed that a minimum of 1000 cases per production batch is used in the plant.

With the help of analysis of the italic data points, we let the model run and compared the outcome to the historical data of the underlined data points. Validating the model can be done on a SKU level (for example: Dreft ADW Original, 33 pieces/bag), or aggregated over all (or part) of the SKUs. It was chosen to validate a model on a single SKU which was completely dedicated to Retailer X (all produced Dreft ADW patches were sold in Retailer X). Validating the model on this single SKU would tell us if the choices that the agents make in the model closely resemble the actions that the agents make in real life, because this data is not distorted with choices made by other agents that are outside of the scope of the model. For example, for a SKU of which Retailer X has only a 10% share would, most probably Procter & Gamble DC would not be triggered solely on the actions of the Retailer X agent in our model.

Historical Replay on a SKU level

In the historical replay on a SKU level it was chosen to analyze the Dreft ADW Original 33CT bags. Retailer X had a 100% share in this specific SKU and was therefore very suitable for analysis and validation of the model. All simulations were run 20 times, but no large differences between these

Store Sales Data & Promotional Forecast Data

As already explained in the data analysis, the sales of Dreft ADW are highly promotion driven and that the sales during the other weeks was quite stable. As the sales are the primary input of the model, the sales that formed the input of the model needed to match the historical sales data. Furthermore the actual promotional sales needed to be used in the model as this is a large chunk of the total sales of Deft ADW.

One of the things that need to be implemented in the model when validating on a SKU level, is the fact that sometimes (due to other SKUs being out of the product range) a sudden increase and then a stable sales number can be noticed. For example in the case of the specific SKU, in the first 20 weeks of the FY 14/15, the regular sales were steady at approximately X cases/week. However in week 21 there was a sudden increase to approximately X cases/week. This sudden increase was built-in into the model. The regular sales were then simulated randomly around X cases per week with standard deviation of 25% of the sales.

Next to this, the promotional forecasts of the FY14/15 were used as an input for preloading procedures and calculations of the uplift. This was included to be able to fully simulate the effect that preloading and forecasting errors have on the service and inventory levels.

In the table below, the tracking of the model sales with respect to the sales actual are shown. As expected, the two nicely coincide. One can see that during promotions (the large peaks); the model sales have a longer 'tail'. This is due to the fact that the model records the sales of the last Sunday during a promotion on the Monday of the next week.

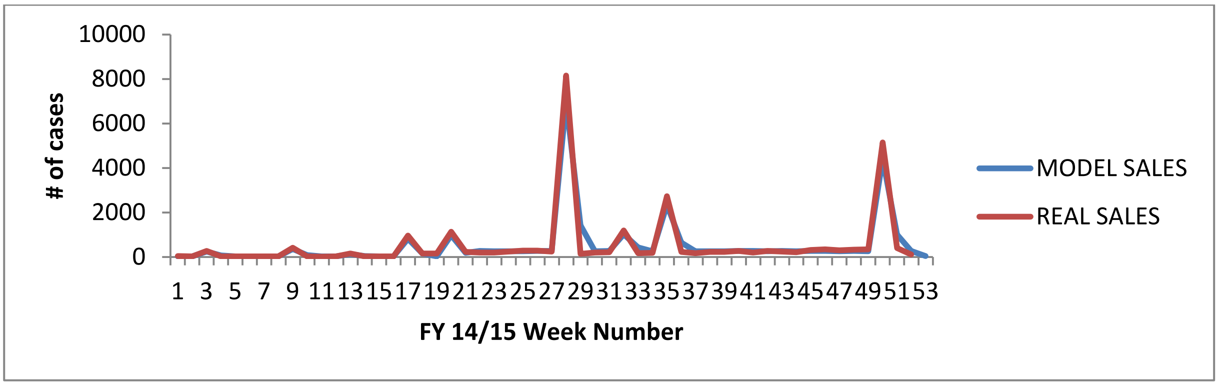

Figure 33: Simulated weekly sales over past fiscal year

It can be concluded that the input for the model is valid, as the total sales coincides to the historical data.

Service As Measured By the Customer

This was measured by the amount of missed cases in replenishing the Retailer X stores from the Procter & Gamble DC. The data analysis showed that for the total collection of Dreft ADW SKUs that are being sold by Retailer X, approximately 58 % of all the missed cases is due to forecasting errors. Zooming in on the single SKU under investigation, the amount of missed cases due to forecasting errors is actually a bit different. The figure below shows a diagram with the root-cause analysis of the specific SKU.

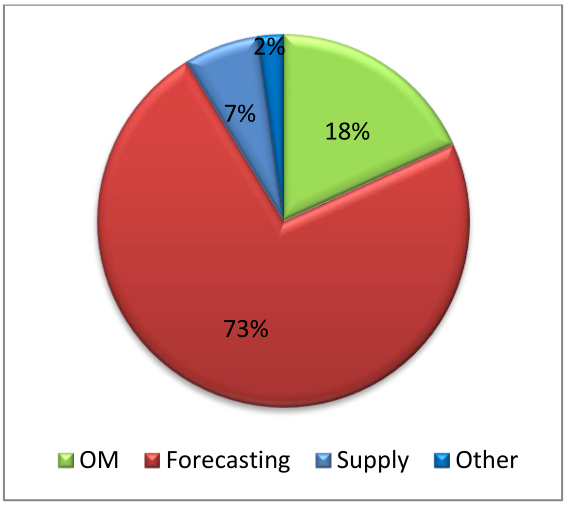

Figure 34: SAMBC root-causes

As one can see is the total amount of missed cases due to forecasting inaccuracy much bigger, up to 73%. Next to that, a share of 7% of supply errors can be contributed to availability issues (out of stocks at

Procter & Gamble), which are also accounted for in the model. A detailed analysis also shows when these hits in SAMBC are taken (which weeks). Because the model does not measure any other root-causes besides forecasting errors, these will not be taken into account. Thus when measuring the SAMBC levels of the historical data and that of the model, the historical data need to be adjusted to only forecasting errors. In the table below, the historical SAMBC data and those of the model are shown.

Table 9: Historical and model SAMBC data comparison

Retailer X DC inventory data

To measure the validity of the replenishment of both the store and the Retailer X DC (and thereby the ordering processes at Retailer X), the historical inventory levels are matched to those that come out of the model. The historical data provided us with the needed safety-stocks that the various agents need to execute. As stated in the previous section, MOQ's of the store and the Retailer X DC are determined by the historical shipping data and stakeholder interviews.

With these parameter inputs, we ran the model and plotted the model data versus the historical inventory data (just as for the sales data). The figure below shows these two graphs.

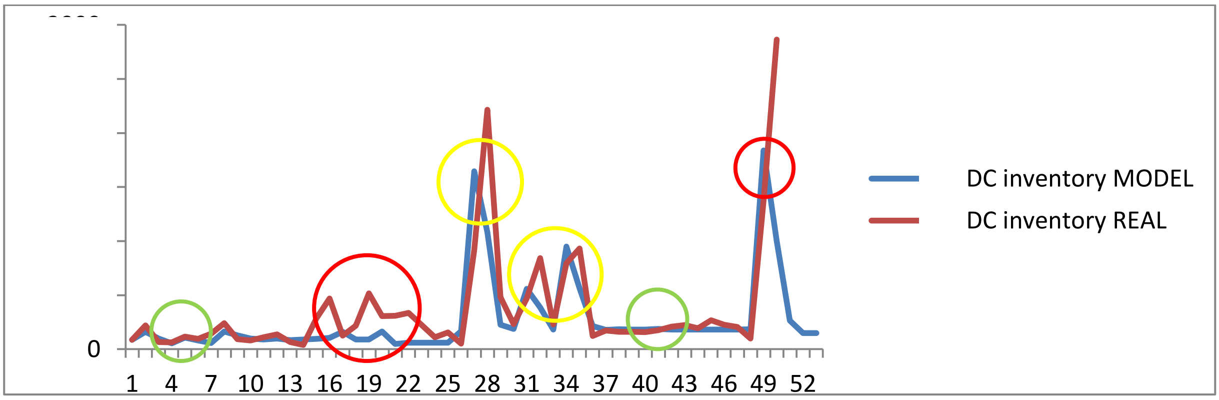

Figure 35: Simulated weekly RETAILER X DC inventory over past fiscal year

The first thing that catches the eye is that the graphs do not coincide as nicely as for the sales data. This is logical, as the sales data is a manual input that on which only a randomizer (within limits) causes small fluctuations. In the case of the Retailer X DC inventory data, two agents 'deform' the input information and through choices in ordering and replenishment values an inventory level is calculated.

Looking more closely at the graphs, one can draw a few conclusions:

- During regular weeks (and small, well forecasted, promotions) the model predicts the inventory levels at the Retailer X DC quite well. The inventory levels quite closely coincide with the historical data (the green circles). This tells us that the ordering and replenishment processes of the Retailer X DC during these weeks are correctly modeled.
- During larger promotions, where the initial forecast did not vary much with the actual sales, the model gives an output that is relatively close to reality (the yellow circles). This can be explained by the following:

- The model uses a standard method of calculating the uplift according to the Monday sales. In real-life, there is business intelligence that comes in the mix. These small deviations might therefore be attributed to differences in the calculation of uplift and therefore deviations in replenishment of the Retailer X DC.

- During large promotions and/or high up/down lifts, the model output does not correctly match the historical data. However the total sales numbers were correct and only deviated a little with the historical data. When asked to experts within Procter & Gamble their explanations were simple:
  - During weeks 16 and 19, there was no initial promotion forecast on the SKU at hand. However sales increased drastically as the SKU was sold on deal (forecasting error). This resulted in an exaggerated reaction in both the Retailer X SDF and amount of replenishment of the DC. Furthermore, it could have been that (while Procter & Gamble normally takes returns after a promotion) it was chosen to leave the inventory at the Retailer X DC for the large promotion that was coming up a few weeks later. All in all, it can most probably be attributed to an out-of-the ordinary human intervention.
  - The large promotions of a few thousand cases (weeks 28 and 49) does not completely match the model inventory levels. This is because the pre-load in the model is logged in the week before the promotion, while in real-life this is recorded in the promotion week. This explains both the shifted peak and the width of the peak.

Procter & Gamble DC inventory data

The last data point that we will use to determine the validity of the model is the inventory level at the Procter & Gamble DC. In this section we will examine if the replenishment and thus order processes centering around the Procter & Gamble DC. Historical data and stakeholder interviews provided the information on safety-stocks, MOQ and other inputs to be able to validate the model.

We executed the model and plotted the historical inventory data of the Procter & Gamble DC with the outcome of the model, just as we have done for the Retailer X DC, and the result is shown below.

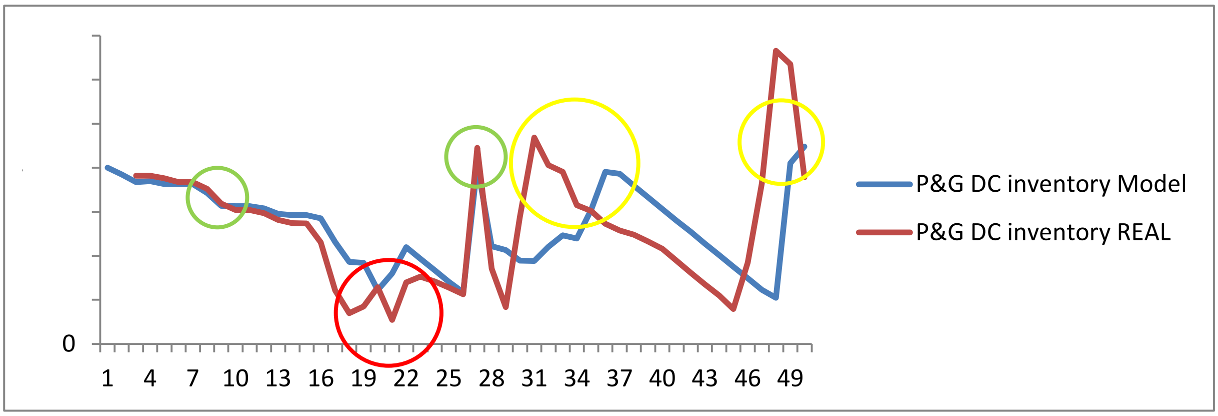

Figure 36: Simulated weekly Procter & Gamble DC inventory over past fiscal year

When comparing the model outcome with the historical inventory data, the first thing that can be recognized is the fact that overall, the model data deviates more from the real-inventory data than the results for the DC of Retailer X. This could mean two things:

- The information on decision making processes (gained from the stakeholder interviews) is not consistent with the real-life decision that are made in this part of the supply chain (thus replenishment decisions of the Procter & Gamble DC).

- There are many more manual interventions made that find their cause in things that are outside the scope of the model (for example: occupied production lines, resulting in earlier production).

Looking more closely there are several points that are of interest, all of them are indicated with either green, yellow or red circles.

- The green circles show data-points that provide ground to believe that the model correctly predicts the inventory level at the Procter & Gamble DC (and subsequently replenishment decisions). During regular weeks (the first green circle), the model closely represents the inventory level at the P&G DC. As no production is taken place (due to the high inventory level at the beginning of the fiscal year), this would indicate that the replenishment process of the Retailer X DC by products from the DC of Procter & Gamble is correctly modeled. The second green circle shows us that for this large promotion (week 28), production is correctly modeled.
- The yellow circles provide some extra attention as the model results are significantly different from the historical data. The first yellow circle shows us that for the two promotion in this period of time, production was triggered earlier than in the model. This causes a shifted peak in the graph. However after this peak, the general trend of the model (a gradual decrease) matches that of the historical data. This also explains the shifted peak at the end of the graph (week 48); production is triggered later in the model than in real-life because of the earlier choice of later production (the period between week 30 & 36).
- The red circle coincides with the red-circle in the graphs of Retailer X DC inventory data. Due to an exaggerated reaction in replenishment of the Retailer X DC, the inventory levels at the Procter & Gamble DC are lower in real-life than in predicted by the model. This is a manual intervention that is out of the ordinary and therefore not taken into account in the model.

Validation through expert consultation

Face validity of the model was investigated by presenting the model to experts. Various expert opinions of different supply chain actors were used in validating different steps and actions of the agents of the model and at the end an overall view on the model was also done. Both the processes and the outcome of the model were presented to experts.

When looking at the processes, choices and interactions of the agents, face validity was already acquired before building the model. The stakeholder interviews were performed during and after the data-analysis, making it possible to already ask the right questions during the interview. The model was heavily based on the information taken out of the interviews with the different stakeholders and therefore the face validity of the performance of each single agent can be regarded as quite high. All interviewees were experts within their department, working at the company or within the department for several years.

Face validity on the overall model was provided by discussing the model with Yannick Vergouwen, Customer Team Logistics Leader Netherlands, and Junie Demange, Customer Team Logistics Leader Manager FBNL. Both agreed that the overall model was a good representation of the real-life system. They agreed that especially because the most relevant processes (as identified by the data-analysis) affecting the KPIs were incorporated in the model, deviations from historical data could be explained by factors that were outside the scope of the model. For example, choices within the factory to produce certain amounts of Dreft ADW at certain times were not incorporated in the model and therefore did not completely match the output of the model. However they both agreed that the model was a good representation of reality, because the output of the model (measured by the KPIs) matched the expected output with the input provided.

As an ABM tries to model the processes, choices of and interactions between the various agents, they did agree that a better representation of this specific case might be possible. However they also agreed that when making the model more case-specific, interesting general learnings of the project might not be found. All in all, it was confirmed by the various industry experts that the face-validity of the model was relatively high.

Validation sub-conclusion

Internal validity of the model

When talking about the internal validity of the model, we want to establish that the model correctly depicts what we it to do. Or better said, the model needs to represent a world with which we can answer the questions that we want to be answered.

When we look at the face validity of the model, we can confirm that the model is valid. Several industry experts and functional experts have been interviewed to obtain the needed knowledge and information to correctly describe the current supply chain. On top of that, the overall model has been discussed thoroughly with industry experts. They have agreed that both agent behavior as well as the outcome can be regarded as valid.

If we then look at the historical replay of the model we can conclude that the model maybe not describes all real-life choices and decisions, but that it does provide a world in which we can answer the questions that we want to be answered. Although it does not resemble on the hour exactly what the inventory levels are at the various DCs, it does describe the overall trends and yields the same average inventory levels. Next to that it very closely describes service level problems that can be observed in real-life. This would conclude that the internal validity in terms of representing a world where we can solve the problem at hand (low service and high inventory), is present.

External validity of the model

Now that we have used the above methods of model validation, what can we say about the external validity of the model? External validity was identified as the extent to which the findings of the experiments could be generalized to other situations. We have identified that the model represents the supply chain of Dreft ADW quite well. Face validity was regarded as relatively high and a historical replay showed that the model matches the reality quite closely. However, does this mean that the external validity is high?

External validity of this model can be regarded as limited due to the fact that the model was built for a supply chain of a specific product, specific retailer and specific manufacturer. Procter & Gamble wanted to know what they could do different/better for the specific case of Dreft ADW and generate general learnings from this case-study that Procter & Gamble could apply to other products and retailers. These are however learnings from the outcome of the model; the model itself is will be harder to use for other case-studies.

To elaborate a bit on that, as the model is agent based, the outcome is largely dependent on the actions of these agents. The ABM is not dependent on specifications of the product, as product sales (POS data) is the input of the model. Assuming that the agents will not behave very differently when handling other products (maybe differences in minimum order quantities or lead-times etc.), the model can certainly be used in situations with other products.

This makes the model more general, but still the aspects of the agent behavior in the model can be quite different it the actors change. For example, the actors within Unilever (#1 competitor of Procter &

Gamble in the Netherlands) could well behave quite different, let alone their choices with respect to replenishments and data-sharing. Next to that, communications with any other retailer than Retailer X could be quite different. Procter & Gamble is a VMI partner of Retailer X, but there are practically no other retailers where such collaboration is in place. All in all one could say that the model itself has limited external validity.

However putting this in perspective, there are lots and lots of different supply chains with different actors, different stakeholders, different decision makers etcetera, all that might behave a little different from the supply chain under investigation. But in the end, one could say that they all have the same goal: sell as much of a product as possible. Therefore the results of experimentation with the computer model can be useful to quantify the possibilities that lie in vertical supply chain collaboration.

8. Model Experimentation Results

In this chapter the outcomes of the model experimentation will be discussed. First the experimental results & data analysis are presented, after which a reflection on the model is given. In Chapter 4 we have identified possible future steps in synchronizing the supply chain by more vertical collaboration. These ‘interventions’, based on the defined concepts of vertical collaboration, were:

- Visibility – availability of real-time information
- Interconnectivity – information release process alignment
- Transparency – use of available up-to-date information

It was chosen to test these interventions based on the historical data and see what would have happened if (some of) these changes were put into practice in the past fiscal year. In total twelve different combinations of interventions were tested with four different production batch sizes.

8.1. Experimentation Results & Data Analysis

In this section the results of the modeling experiments will be presented. At the beginning of each experiment, an input decision needs to be made on the production batch size of the Dreft ADW production plant in Mechelen. Therefore the results of the experiments are presented with respect to the initial decision on the production batch size.

Production batch size 2000

At the start of this experiment, the production batch size was set at 2000 cases. This means that when production is triggered, at least 2000 cases would be produced. Currently, the batch size of the manufacturing plant in Mechelen is 2000 cases, what is a total runtime of 4 hours. The output of the model was measured in the KPIs determined by Procter & Gamble, thus SAMBC and inventory at Procter & Gamble DC. The KPI costs will be discussed in a later section. In the table below, the aggregated outcomes of the set of SKUs used in the modeling experiments for a batch size of 2000 cases is shown.

Table 10: Aggregated SKU experimental results with a production batch size of 2000 cases

When looking at the table, first of all, experiment 1 (the base experiment) was a simulated re-run of last fiscal year. All improvements in service and inventory experiments are measured to this reference point.

Overall, it can be stated that with the proposed supply chain interventions both service and costs can be improved. This would mean that sharing information is indeed valuable and can circumvent the service-inventory dichotomy. In the remainder of this section, the focus will be on the most prominent or remarkable results of the experimentations.

Visibility

Experiment 2 shows the effect that the use of POS-data in replenishment in the supply chain has with respect to the reference; experiment 1. In short, the experiment means that the safety buffers in ordering are being cut out. The main gain is certainly the lowering of average inventory level by 7%, but next to that there is a small increase in service level. The win in total inventory can clearly be attributed to the fact that there are fewer safeties in the supply chain (reduction of the bullwhip effect). The win in service might be a little harder to explain. This might be attributed to the fact that using the POS-data to replenish daily what is needed, the total amount of missed cases will be lower if there is no inventory (as less cases are ordered).

Connectivity

Experiment 3 shows the results in terms of SAMBC and inventory when a Monday afternoon release is in place. Apart from the fact that the experiment shows that there is clearly an increase in SAMBC, it also shows the consistency of the model with respect to the inventory. In theory, no change in inventory should occur when this intervention is in place and the model confirms this. The increase in service level can be attributed to the fact that the uplift in sales is communicated earlier and therefore the misses that normally occur on Tuesday are now covered.

Experiment 5 shows the scenario where full release process alignment between Retailer X and Procter & Gamble is in place. As this scenario makes it possible to replenish the store and Retailer X DC with what is sold daily, a decrease in both service and inventory can be expected. The model shows that both service and inventory levels can improve drastically.

Transparency

The experiment that solely measures the impact of creating more transparency in the supply chain is experiment 7. This experiment shows something remarkable. The model predicts that there is huge decrease in inventory (as would be expected), but also a decrease in service level! The decrease in inventory was expected, as the plant uses more up-to-date information to produce the need of the customer. However, one would expect that this would not result in a service hit.

When looking for the root-cause behind this decrease in service, it can be seen that this root-cause is an availability issue at the Procter & Gamble DC (so no product available) **on a single promotion on a single SKU**. In this specific case, production is triggered too late and the uplift cannot be covered by the safety-stock. This results in such a large amount of missed cases that it has such a large influence on the total SAMBC. All in all, one could state that this decrease in service can be accounted to the model and that in a real-life situation there might have been some manual interventions that would have covered for this to happen.

Combinations of concepts

In the above sections the focused was on the effect that a single supply chain intervention has on the KPIs Service and Inventory. Here we will focus on the most important findings that combinations of introducing these concepts in the supply chain have on these KPIs. We will discuss the scenarios that subsequently need more willingness to collaborate from the retailer (as discussed in Chapter 3).

1. Implement a Monday afternoon release during promotions: This would require a change in the processes of Procter & Gamble, but not so much for Retailer X. This scenario is already described under the section connectivity above.
2. Create transparency in production planning: In this scenario, both a Monday afternoon release during promotions and transparency in production planning are implemented in the supply chain. This is simulated by the model in experiment 9. The model shows that the average inventory at the Procter & Gamble DC will be 15% lower than in the reference experiment. Next to that, with respect to experiment 1, service will be improved. However, if one compares scenario above (with only a Monday afternoon release), the total gain on service is less. This can be attributed to the lowering of inventory and becoming a slimmer supply chain.
3. Fully synchronize order release processes: The next step would be to not only implement an order release at Monday evenings during promotional weeks but also to fully synchronize the order release process between Procter & Gamble and Retailer X. This scenario is modeled in experiment 11. It shows that there are both improvements in inventory and service compared to the reference experiment 1. However, compared to the previous scenario, the inventory level seems to be constant while the service level improves. This would indicate that there is a maximum to the improvements in service and inventory when these interventions are put into practice.
4. Use POS-data throughout the chain: the last scenario under investigation is a supply chain where the above interventions are put into practice and POS-data is used throughout the supply chain to guide replenishment. This scenario is tested in experiment 12. It can be seen that by basing replenishment decisions on the POS-data, both service can be increased and the average inventory level can be lowered. When looking at all the different scenarios the most benefit can be gained in this scenario both on inventory (-20%) and service (+2.18%).

Interestingly enough, combinations of more connectivity, transparency and visibility cannot simply be calculated by summing, averaging or multiplying the values that can be found when implementing one of the interventions in the supply chain of Dreft ADW. Some combinations amplify effects whilst others counteract the effect that the interventions have on Service and Inventory.

Production batch size 1000 cases

The 12 experiments, performed in the previous section for a production batch size of 2000 cases, have also been run with a production batch size of a 1000 cases. The experiments and results expressed in terms of the KPIs are shown in the table below.

Table 11: Aggregated SKU experimental results with a production batch size of 1000 cases

Aggregated	Visibility	Connectivity	Transparency	SAMBC	SAMBC Δ%	Average invt. PG DC	Av. Invt. Δ%	Av. Invt. Δ% with MOQ 2000
Experiment 1	0	0	0		-	3548	-	-26%
Experiment 2	+	0	0		-0.48%	3248	-8%	-33%
Experiment 3	0	+	0			3584	1%	-26%
Experiment 4	+	+	0		-0.04%	3170	-11%	-34%
Experiment 5	0	++	0		1.22%	3197	-10%	-34%

Experiment 6	+	++	0		1.65%	3054	-14%	-37%
Experiment 7	0	0	+		-0.17%	3012	-15%	-38%
Experiment 8	+	0	+		-0.40%	2876	-19%	-40%
Experiment 9	0	+	+		1.40%	3062	-14%	-37%
Experiment 10	+	+	+		0.45%	2909	-18%	-40%
Experiment 11	0	++	+		1.43%	3021	-15%	-37%
Experiment 12	+	++	+		1.90%	2902	-18%	-40%

The first thing to notice in the table is that the average inventory level for the reference experiment (experiment 1) with a production batch size of a 1000 cases is 26% lower when compared to experiment 1 with a production batch size of 2000 cases.

Overall, the relative outcome of these experiments is consistent with the results from the experiments done with a production batch size of 2000 cases. Information sharing is valuable and can result in both an improvement in service and inventory. However, looking more closely at the specific experiments, there are some interesting results when comparing the results of the different batch sizes.

Visibility

When the experiment is run with increased visibility (experiment 2) the inventory is lowered as expected, but in contrast to running the experiment with a larger batch size, the use of POS-data lowers the service level. This would actually be more in line with the thought that lowering inventory by cutting out safeties would result in lower service levels. Using POS-data in combination with a smaller batch size might be cutting out inventory at the wrong place in the supply chain (at the Retailer X DC), resulting in lower service levels.

Connectivity

Experiment 3 and 5 show the scenarios with increased connectivity between Retailer X and Procter & Gamble. These model experiments shows more or less the same results as the same experiment with a production batch size of 2000 cases. In experiment 3, there is an increased service level and a more or less stable inventory level. Experiment 5 shows that by fully synchronizing the order release processes, both service and inventory levels can be improved.

Transparency

Experiment 7 shows again a scenario with solely increased transparency in the supply chain of Dreft ADW. The results demonstrate again that there is a large decrease in inventory (as more accurate data is used in production), but at a cost of lower service level. The choice for later replenishment of the Procter & Gamble DC comes at a cost; a big uplift cannot be covered by the stock that is available and lead-times are too long to replenish the Procter & Gamble DC in time and these two combined result in misses in service.

Combinations of concepts

Just as for the experiments done with a production batch size of 2000 cases, combinations of implementation of the above concepts was also under investigation with the smaller production batch size of 1000 cases. The same line of analysis as that has been done in the previous section is done here.

1. Implement a Monday afternoon promotion release: This yields the same outcome as for a larger batch size; increased service and approximately a constant inventory level.
2. Create transparency in production planning: Broadly speaking, creating more transparency in the production planning yields in this scenario the same results as in the scenario where a production batch size of 2000 cases was simulated. This means that there is an increased level of service and

lower inventory. However, it can be seen that creating transparency in combination with a Monday afternoon order release boosts service even more (this in contrast to what can be seen for the same scenario with a production batch size of 2000 cases)

3. Fully synchronize order release processes: Fully synchronizing order release processes together with increased transparency in production planning show the same findings as for a production batch size of 2000 cases, (small) increase in service and decrease in inventory.
4. Use of POS-data in replenishment: This is the final step in optimizing the supply chain; using POS-data for replenishment of the various parts of the supply chain. Experiment 12 shows these results and the results are consistent with what can be found in Table 11. Increased service and a lower average inventory level.

One can say that overall, the findings in these experiments are consistent with the results from the modeling experiments with a production batch size of 2000 cases. However, there are a few results that are inconsistent and might need some more investigation. But before we dive into these data points we will discuss the same experiments for an even smaller production batch size of 500 cases. This might help us better understand what is going on in the separate experiments and which factors influence the outcome and in what way.

Production batch size of 500 cases

The second to last batch size under investigation is a production batch size of 500 cases. Again the same experiments are done as for the scenarios with batch sizes of 2000 and 1000 cases. A similar table to the ones shown in the previous sections is displayed below. Experiment 1 is a re-run of the last fiscal year with the initial choice to have a batch size of 500 cases.

Table 12: Aggregated SKU experimental results with a production batch size of 500 cases

Aggregated	Visibility	Connectivity	Transparency	SAMBC	SAMBC Δ%	Average invt. PG DC	Av. Invt. Δ%	Av. Invt. Δ% with MOQ 2000
Experiment 1	0	0	0		-	3078	-	-36%
Experiment 2	+	0	0		-0.47%	2828	-8%	-41%
Experiment 3	0	+	0		0.98%	3149	2%	-35%
Experiment 4	+	+	0		0.04%	2808	-9%	-42%
Experiment 5	0	++	0		1.05%	2823	-8%	-42%
Experiment 6	+	++	0		1.48%	2595	-16%	-46%
Experiment 7	0	0	+		-0.45%	2533	-18%	-48%
Experiment 8	+	0	+		-0.37%	2470	-20%	-49%
Experiment 9	0	+	+		1.02%	2586	-16%	-46%
Experiment 10	+	+	+		0.35%	2495	-19%	-48%
Experiment 11	0	++	+		1.06%	2536	-18%	-47%
Experiment 12	+	++	+		0.84%	2442	-21%	-49%

As can be extracted from the last column of the table, reducing the batch size inherently means that the total average inventory at Procter & Gamble reduces by 36%. Next to that, one could compare the service level of all reference experiments of the different batch sizes. It can be seen that with a batch size of 500 cases there is an increase in service level with respect to the larger batch sizes. A case could be made that reducing the batch size thus increases the service level as production might be triggered earlier or at other points in time than with the larger batch sizes. Production will then be tailored to the needs of the customer creating a pull-mechanism instead of a push supply chain. In the next sections, we will again take a closer look on the effect of visibility, connectivity and transparency.

Visibility

Experiment 2 shows a supply chain with only increased visibility by the use of POS-data to guide the replenishment choices in the chain. It can be seen that cutting out safeties that are built in through safety factors in the ordering process, the inventory can be lowered. However, this comes at the expense of the service level. This is in line with the findings of the same scenario and a batch size of a 1000 cases, but not in line with the findings of using POS-data with a batch size of 2000 cases. This might confirm the fact that using POS-data in combination with a smaller batch size might be cutting out inventory at the wrong place in the supply chain (at the Retailer X DC), resulting in lower service levels.

Connectivity

The experiments 3 and 5 show the different degrees of connectivity at Retailer X for a production batch size of 500 cases. The model shows the same pattern of results as for larger batch sizes; increase in service and a constant or decrease in inventory for experiment 3 and 5 respectively.

However, it can be seen clearly that the effect these interventions have on service level are (relative to the reference experiment) lower than for larger batch sizes. Then again, looking at the absolute values of the service levels they do not vary that much (all around 98.60% service). It might thus be the case that there is an absolute limit to the improvement in service that can be achieve by increasing the connectivity between Procter & Gamble and Retailer X, independent of the batch size.

Transparency

At last experiment 7 investigates the effect of transparency in the supply chain. It shows the same pattern as in the other experiments with larger batch sizes; a decrease in inventory, but also a lower service level. The explanation for the effect that has been given in the previous section most probably holds also for the model results with a production batch size of 500 cases. Thus a big uplift cannot be covered by the stock that is available and lead-times are too long to replenish the Procter & Gamble DC in time.

Combinations of concepts

The same combinations as reviewed in the previous sections on combinations of visibility, connectivity and transparency will be discussed below while also retaining the same line of analysis.

1. Implement a Monday afternoon release during promotions: this scenario is simulated in experiment 3 and the results show an increase in service level while slightly raising the average inventory level. No large deviations in the results can be found in the same experiments with larger batch sizes.
2. Create transparency in production planning: creating transparency next to a Monday afternoon order release is simulated in experiment 9. No significantly different results can be found in this experiment with batch size of 500 cases with respect to larger batch sizes. A decrease in inventory and an increase in service are shown in the simulations.
3. Fully synchronize order release processes: by fully synchronizing the order release processes next to transparency in the production planning, the most improvement is at the inventory side. Service does not improve much with respect to step 2 (above), but compared to experiment 1 there is still more than 1% increase in service.

4. Use POS-data throughout the chain: interestingly enough, creating visibility in the chain by using POS-data results in a lower service level with respect to the previous step (number 3). This is in contrast to the findings of the same experiments for larger batch sizes. In this scenario the model suggests that the supply chain becomes too lean when POS-data is used in combination with a small batch size. Too much inventory might be cut-out of the chain with respect to the lead-times in the chain.

The above findings show us that the results of the modeling are more or less consistent with the findings when the same simulations are done with a larger batch size. However, there is one main difference between the simulations on a batch size of 500 cases and larger batch sizes. Due to the reduction in inventory by reducing the batch size, the safety margins in the supply chain become too small. They become so small, that removing the safety factors in the ordering process makes the total supply chain too lean with respect to the lead-times. It means that sudden (large) changes in demand cannot be covered by safeties and cannot be supplied in time with the existing lead-times. Increased connectivity between Retailer X and Procter & Gamble counteracts this fact, but the service levels that can be achieved with a larger batch size are cannot be achieved in this scenario.

Production batch size of 100 cases

The smallest batch size under investigation was a batch size of 100 cases. We chose this as the smallest batch size, because the current minimum order quantity of Retailer X at the Procter & Gamble DC is also 100 cases. This is (roughly) one pallet per production run and would take 12 minutes to complete with the existing production lines. Compared to the current day production batch size of 2000, this is a 20 fold (!) reduction. Just as for the other batch sizes, in the table below the 12 different experiments and their outcomes are shown.

Table 13: Aggregated SKU experimental results with a production batch size of 100 cases

Aggregated	Visibility	Connectivity	Transparency	SAMBC	SAMBC Δ%	Average invt. PG DC	Av. Invt. Δ%	Av. Invt. Δ% with MOQ 2000
Experiment 1	0	0	0		-	2748	-	-43%
Experiment 2	+	0	0		-0.58%	2480	-10%	-49%
Experiment 3	0	+	0		1.22%	2774	1%	-43%
Experiment 4	+	+	0		-0.21%	2464	-10%	-49%
Experiment 5	0	++	0		1.11%	2453	-11%	-49%
Experiment 6	+	++	0		1.20%	2242	-18%	-54%
Experiment 7	0	0	+		-0.09%	2213	-19%	-54%
Experiment 8	+	0	+		-0.55%	2127	-23%	-56%
Experiment 9	0	+	+		1.10%	2243	-18%	-54%
Experiment 10	+	+	+		-0.01%	2176	-21%	-55%
Experiment 11	0	++	+		1.07%	2213	-19%	-54%
Experiment 12	+	++	+		0.51%	2116	-23%	-56%

Overall, the first thing that can be taken from this table is the fact that due to the smaller batch size, the total amount of inventory (with respect to a batch size of 2000) is hugely reduced (up to 56%). This comes at the cost of a lower service level, as the highest service level that can be achieved with any supply chain intervention is much lower than with a larger production batch size. Of course, this can easily be explained by the fact that implementing such small batch sizes will reduce the safety margins within the chain (with the current decision making processes in place) to a point that these are not sufficient anymore. Also the base service level (SAMBC at experiment 1) is again significantly higher than the current state. This would confirm the suspicion that a smaller batch size would be better able to tailor the supply chain to the needs of the customer as explained in the previous section. We will now focus on the separate interventions to have a closer look at the effect they have on the supply chain KPIs.

Visibility

Experiment 2 shows the effect of increased visibility in the supply chain. Just like for a batch size of 500 cases, it decreases both inventory and service level. This would confirm the hypothesis that the built in safety margins will get too low within the boundaries of the current supply chain execution and decision making processes; we are cutting out margins that do not exist anymore.

Connectivity

The same pattern for a batch size of 500 cases (and larger) can be seen for an ever smaller batch size of 100 cases; an increase in service level when implementing a Monday afternoon release during promotions while maintaining the same inventory level and both an increase in service level and a decrease in inventory when fully synchronizing the order and replenishment processes of Retailer X and Procter & Gamble.

One can also see that the absolute service levels (thus absolute missed cases) hovers around the same level for all experiments with different batch sizes. This would mean that there is an absolute limit to the improvement in service that can be achieve by increasing the connectivity between Procter & Gamble and Retailer X, independent of the batch size.

Transparency

Overall, the experiment that tests transparency (experiment 7), shows the same results as are found in the experiments with larger batch sizes; lower inventory and lower service. There is, however, one thing that catches the eye. Compared to larger batch sizes, the hurt on service is much less for a batch size of 100 cases. One could try to explain this with the fact that because the batch size is so small, the supply chain is already very much tailored to the needs of the customer; producing exactly what is demanded by the customer.

Combination of Concepts

At last for this batch size, the same combinations of visibility, connectivity and transparency as for the larger sizes will be under discussed:

1. Implement a Monday afternoon release during promotions: simulated in experiment 3 and discussed in the section on connectivity, no variations from the same experiment with larger batch sizes can be identified.
2. Create transparency in production planning: simulated in experiment 9, again no variations are found with the outcomes of the experiments for larger batch sizes. This means that there is both an increase in service and decrease in inventory with respect to experiment 1
3. Fully synchronize order release processes: experiment 11 shows this specific scenario and also for this experiment there are no interestingly great differences with respect to the results discussed in the previous sections. One could make the case that for smaller batch sizes the total increase in service level is less (X vs.). This might be a model error (as it falls within the standard deviation), but it can also be explained by the fact that there is just not enough inventory to cover the forecasting errors due to the small batch sizes (and subsequent lower production).

4. Use POS-data throughout the chain: maybe the most interesting scenario of the four, as it provides new insights (or moreover: confirms earlier thoughts) on the value of POS-data in the chain. The same phenomenon of using POS-data as observed in the same experiment with a batch size of 500 cases is seen here. The service level drops and this time even more than in the experiment with batch size of 500 cases. This confirms our suspicion that the supply chain becomes too lean when implementing both the use of POS-data and a small batch size. It must be said that we assume that all other processes in the supply chain stay the same (calculation of safety-stocks, safety-margins etc.).

These experiments confirm certain hypotheses developed after the runs with 500 cases. Due to the reduction in inventory by reducing the batch size, the safety margins in the supply chain become too small. When moving into this regime POS-data becomes less valuable, while forecasting accuracy becomes even more valuable. Thus when the assumptions, boundary conditions and decision making processes in the model stay the same, the win in inventory is huge, though the increase in service level will never meet the values that can be achieved with a larger batch size. Next to that it must be noted that for making these scenarios happen, change-over times need to be reduced 20 times to be able to produce the products for the same costs and the full benefit of the interventions can be harvested.

Other remarkable results

There are a few other results in the various experiment that raise an eyebrow. These will be discussed in the next section.

Experiment 8 – all batch sizes

What can be seen in experiment 8, combination of increased visibility and transparency, is that it is not in line with the findings of the experiments on the concepts separately (experiments 2 and 7). The reduction in inventory is as expected, but when one looks at the service level, something strange can be observed. What one would expect is that the service level drops even more than the lowest service level of the two separate experiments. However, what can be observed is the opposite; the service level increases with respect to the lowest service level. This can be explained by the following.

Earlier in this chapter it is explained why the service level decreases by increasing transparency; it could be attributed to a Procter & Gamble DC out of stock during one promotion of a single SKU. The uplift is so large that when producing for a promotion in a later stage, there is not enough safety stock to cover this uplift. However, if one would then use POS-data to plan replenishment (thus less safety in ordering), less product would demanded from the Procter & Gamble DC. This would this mean that less cases are demanded during the time that the Procter & Gamble DC is out of stock and thus a higher service level.

Experiment 9 – all batch sizes

In experiment 9, combination of full connectivity and increased transparency, another interesting result in inventory reduction can be seen. While both of the separate experiments (experiments 5 and 8) show a large decrease in inventory, the combination of the two does is not as large as one would expect. This would suggest that both interventions cut away the same part of inventory. This in contrast to, for example, combining visibility with either of the other concepts. Visibility cuts away safety factors that are built in in the ordering process. Transparency and connectivity relate to cutting away overproduced inventory. Therefore combining visibility with either transparency or full connectivity does result in a lower inventory levels and the other does not.

Sub-conclusions

It can be concluded that the batch size has a significant effect on the impact that the different interventions have on the supply chain of Dreft ADW. Next to that, regardless of the batch size, service and inventory levels can be improved with respect to the current day situation.

As expected, a lower inventory can be achieved by lowering the minimum batch size of the material, which is a positive effect as it results in lower costs. However, the model shows that the gains in service are lower when the batch size is reduced. Where certain scenarios of increased vertical collaboration between Procter & Gamble and Retailer X show large service improvements if the batch size is not reduced (or only slightly reduced), the same experiments do not yield these results for a smaller batch size of 500 cases. Both the use of POS-data (eliminating the safety margins in the ordering process) and increased transparency (reducing the production-push of products) are drivers in the reduction of inventory.

The model shows that increased connectivity between Retailer X and Procter & Gamble is the main driver behind better service levels. This can of course easily be explained by the fact that the data analysis already showed that the main problem in the low service levels does not lie in lead-time or inventory. It is the ordering process that is not aligned with replenishment and causes the low service levels. In this research, increased connectivity is a specific case that solves this problem and thus explains the increase in service level.

8.2. Model Reflection

Before we move forward to a discussion on the results of the model, we will first reflect on the modeling choice, applicability and performance.

Choice for Agent Based Modeling

At the start of the project we have looked at the benefits and limitations of Agent Based Modeling. Based on this analysis and an initial assessment of the problems and root-causes behind these problems we have chosen to use ABM as the modeling tool. However the question remains, was this choice in hindsight the right one, as literature showed that other options were also available for modeling the supply chain.

The initial assessment and subsequent identification of the research problem gave the impression that we were dealing with a complex socio-technical problem. Actors seemed to exhibit complex behavior and interaction between these actors within the supply chain was thought to be complex and nonlinear. Next to that, all actors in the supply chain seemed to be different, resulting in a heterogeneous system. In short, there was enough basis to assume that ABM was a suitable method for modeling.

In hindsight we can say that using ABM in this research might have been like taking a sledgehammer to crack a nut. Decision making processes we thought would be complex and nonlinear turned out to be cast in concrete or contractually agreed upon, or more importantly the identified agents will in real-life never have the authority to make decisions that would influence the supply chain in a way that can be noticed on a major scale. Next to that, the behavior of the agents was not as complex as we thought it would be (and more restricted to company guidelines) and especially the ability of ABM to show emergent behavior could not be leveraged in the current set-up (or goal) of the research. The model works and seems to be valid in its calculations of the supply chain KPIs, but it does not leverage the full potential of ABM.

In the current set-up, we were mainly focused on what the benefit would be for Procter & Gamble when certain interventions were made for the supply chain of Dreft ADW. The approach was to model the current supply chain and subsequently test the effect of interventions that were based on the concepts of vertical collaboration in the supply chain. These interventions were designed on paper after a data-analysis on the root-causes of the data-analysis on the current supply chain. Subsequently, these interventions were implemented (or programmed in the model) after which they yielded results in the quantitative benefits of the supply chain KPIs. When ABM would have been correctly used, it should have been the other way around; interventions for the real-life supply chain could have been identified with the help of the model. Subsequently the KPI improvements would have been calculated and would (ideally) yield the same (or even better) results.

Concluding: was ABM the right modeling tool? Most probably not. Using ABM did yield results that were interesting for the research (and were the results we were looking for), but the same results could have been withdraw from a model based on another (more mathematical) technique. ABM is an easy to program tool (especially in NetLogo), which made it tempting to use in this project. This is not necessarily wrong, but using ABM created a certain expectation of the research that is not met. How to better use ABM in future research on the same subject will be discussed in the recommendations.

Applicability and performance of the model

As stated in the previous section, the model is readily applicable to the current research. The model is internally valid and provides quantitative solutions to the research problem. It can be applied to the supply chain under investigation, but also to other products for the customer-manufacturer combination of Procter & Gamble and Retailer X. This also already shows the limitations of the model. The external validity is limited, because we have modeled a specific customer-manufacturer-product combination. This results in a very case-specific model that cannot be used for other customer-manufacturer combinations.

The results of the model for the specific case of Dreft ADW can possibly be generalized to other supply chains, as the overall findings indicate what the general trade-offs are. It might not be possible to linearly extrapolate the specific (absolute) KPI improvements to other supply chains (or product categories), but it does provide insights on what trade-offs need to be made in designing a supply chain with enhanced vertical collaboration.

The results of the model seem to be valid and provide some interesting insights (which will be discussed in a later chapter). We might thus conclude that the performance of the model is relatively good. With the results, we will be able to answer the core-research question (and sub questions) and meet the deliverables of the project.

9. Model Experimentation Discussion

In this chapter the general trends that can be observed in the results of the modeling experiments will be discussed. By conducting such a discussion, we would like to provide a somewhat broader perspective on the findings than just the impact of the various scenarios on the supply chain of Dreft ADW. We will do this by discussing the results in a number of ways:

1. Effect of batch size reduction
2. Effect of increased vertical collaboration
3. Value of information

The outcome of the discussion should provide us with the needed analysis to answer the (sub-) research question(s).

9.1. Effect of batch size reduction

In the previous chapter we have shown the results of the different scenarios with increased vertical collaboration for various batch sizes. The four batch sizes that were under investigation are:

- 2000 cases
- 1000 cases
- 500 cases
- 100 cases

The separate batch sizes have already been discussed, but an overall analysis on the effect of batch size reduction has not yet been made. When comparing the different batch sizes to each other, the simple conclusion can be drawn that a reduction in batch size is inherently related to a decrease in inventory, as is shown in the graph below.

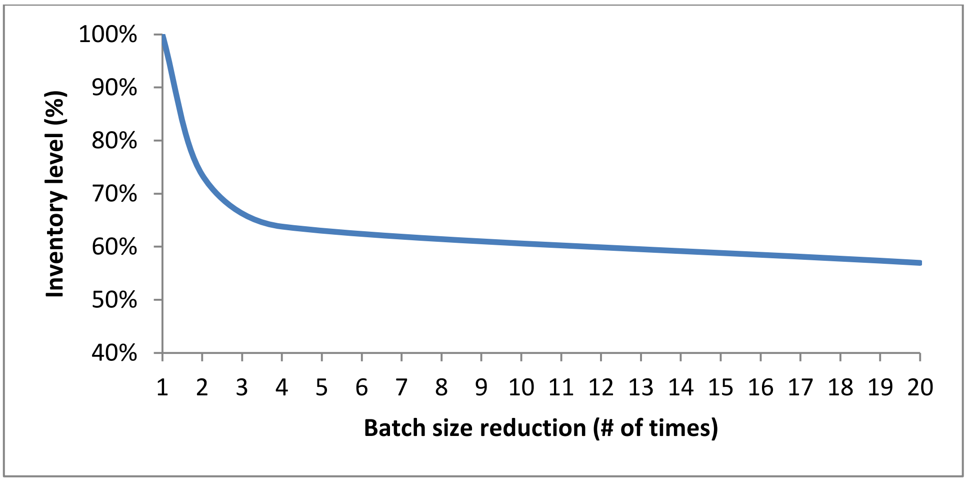

Figure 37: Inventory reduction vs. batch size reduction

The graph shows that by just reducing the batch sizes, the maximum gain in inventory is more than 40%. This is a particularly important chart, as a batch size reduction is often linearly related to the change-over time reduction. Thus reducing the batch size from 2000 to 1000 cases, would mean that the changeover time should also be dissected; changeover procedures need to be performed twice as fast. However, the next 900 cases would mean that the changeover time needs to be reduced 10 times more! It is therefore rather important to mention that the biggest reduction in inventory (in %) occurs when dissecting the batch size from 2000 cases to 1000 cases.

Overall, the analysis showed that the amount of inventory reduction approaches a maximum of approximately 45-50% inventory reduction. Which means that if Procter & Gamble would reduce their batch size to a single case, inventory reduction will never be more than 50% (with the current supply chain settings).

Free cash

Looking at the specific case of Dreft ADW, we can calculate the cash that would come free with the inventory reduction by decreasing the batch size. These calculations are based on the formula to describe the cost of stock immobilization:

$$Cost\ of\ stock\ immobilization = cost\ of\ goods\ sold \times WACC$$

With a WACC of 7%, to the total cash that would come free when reducing the batch size is given in the table below:

Table 14: Simulated free cash due to batch size reduction

However there are of course downsides to batch size reduction. Changeover times are not easily reduced, thus a decrease in batch size will (at least on the short term) be accompanied by extra downtime in production. This will inflate the total cost of production, bringing down the free cash that can be gained by reducing the batch size. Below, a cost calculation of increased downtime is given.

Changeover costs

We calculate the changeover costs in the supply chain of Dreft ADW with the following equation.

$$Changeover\ costs = costs\ per\ minute\ \times average\ downtime\ \times\ number\ of\ changeovers$$

The formula speaks for itself and the number of changeovers is taken over the past fiscal year (so it can be easily compared to the other results).

We have based the cost calculations of changeovers on the absolute number of extra production runs that would have been made when the batch size was reduced. A minimum batch size of 1000 cases does not necessarily mean that there are twice as much production runs needed for the set of SKUs. For example, promotions are often still produced in batches larger than 1000 cases.

In the table below the thee variables are given for the different batch sizes.

Table 15: Changeover costs with varying batch size

As displayed by the table, the cost and total downtime per changeover are assumed to be constant for all batch sizes. Hence, it comes down to the amount of changeovers that are needed. We assumed correctly that bisecting the batch size does not mean that there are twice as much production runs (and thus change-overs). This results in (an estimate of) the changeover costs in the Dreft ADW supply chain on the selected data set, shown in the bottom row of the table. As anticipated, the increased cost of production changeovers for small batch sizes is disproportionally large to the current batch size of 2000 cases.

Before a conclusion will be drawn on the overall quantitative benefit of reducing the batch size, there is one effect left that requires a little more investigation. It could be seen that (however small) the service level is also influenced by the size of the production batch.

Service level

Decreasing the batch size also has an effect on service level. The general trend is that a decrease in production batch size increases service level (as shown in the graph below). This can be explained by the fact that a reduced batch size would enlarge the frequency of production, better tailoring the needs of the customer. If the production department works with smaller batch sizes, production is more agile and could better react to sudden customer demand.

Figure 38: Batch size vs. SAMBC

One can see that when the batch size is decreased 20 times (thus a batch size of 100 cases), the service level diminishes again. This would be explained by the fact that inventory is reduced too much for the supply chain lead-times. Normally this would probably be counteracted by enlarging the safety stock, but the model uses constant safety-stock; explaining the lower service level in the results. Now that these insights in service level are known the question arises: how can one translate an increase (or decrease) in service level to actual cost benefits/losses?

The service level was measured as the amount of cases of Dreft ADW that could not be delivered to the store when they were ordered. When a case is missed, it might have an effect on the actual amount of products sold in the store and leads to a lower revenue. Research has shown that at least 35% of the intended sales becomes a cost for the manufacturer (thus an expense for Procter & Gamble). Based on the acquired model data and this estimate of the cost for the manufacturer, it is possible to work out the total costs that come with an increase of decrease in SAMBC. The equation that can be used to calculate these costs is:

$$Costs = missed\ cases \times cost\ per\ case \times 35$$

In the table below the benefits of decreasing the batch size are shown.

It can be seen that the cost benefits that are involved with an increased service level are relatively small and are practically negligible when compared to the free cash benefits and changeover costs.

Sub-conclusion

To conclude this section an overview of the costs (changeover costs) and benefits (free cash and service increase) is given. In the figure below the benefits and the costs are stated as a function of the various batch size reductions.

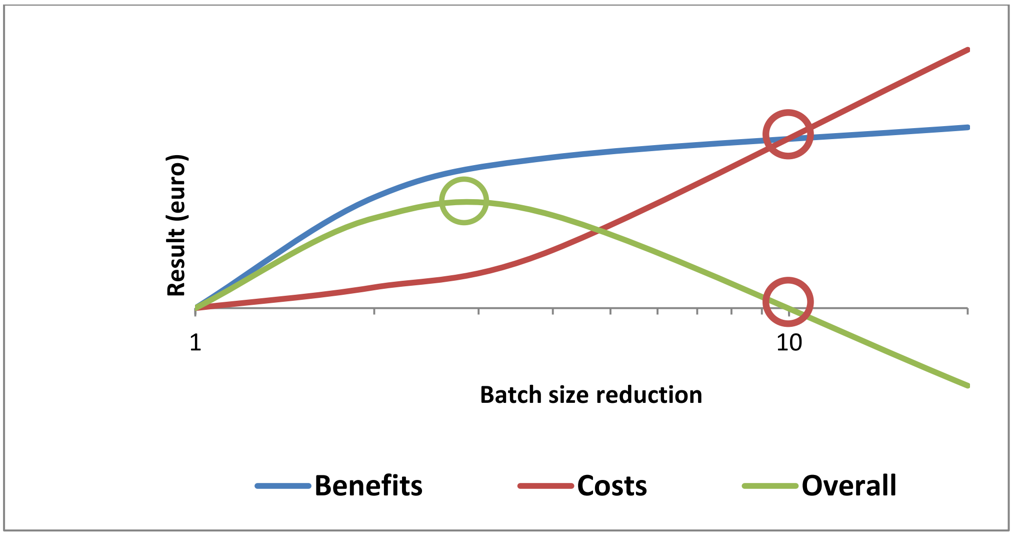

Figure 39: Batch size reduction vs. cost and benefits

All in all, one can say that it is valuable for Procter & Gamble to reevaluate their inventory policy and also their production batch sizes. It can be seen from the cost calculations that the decrease in inventory outweighs the costs that come with increase in downtime. However, this can only be said to batch sizes up to a certain level. The graph shows that the batch size could be reduced roughly 10 times (resulting in a batch size of 200 cases) without the cost outweighing the benefits. This same graph shows us that by decreasing the batch size 3 times (resulting in a batch size of ± 650 cases), the most benefit can be gained.

9.2. Effects of increased vertical collaboration

We have seen from the results of the modeling experiments that the various concepts of vertical collaboration all have a different effect on the performance of the supply chain. We have provided an overview of the results, specific for each batch size, here we will try to give a broader view on the findings of each separate concept. In this section, only the quantitative results from the model will be discussed, followed by a translation to the value in Euros in the next section.

Visibility

Visibility, embodied in the experiments by the sharing and use of POS-data throughout the chain, is a measure that has both an effect on inventory as well as on service. The most important and outstanding result is that visibility not always leads to better overall supply chain performance.

When implementing the use of POS-data for the current supply chain (with a batch size of 2000 cases), the overall supply chain performance would increase (both service will go up and inventory will decrease). Moving, however, to smaller batch sizes, there will be a hurt in service that is undesirable. This can be seen in the figure below.

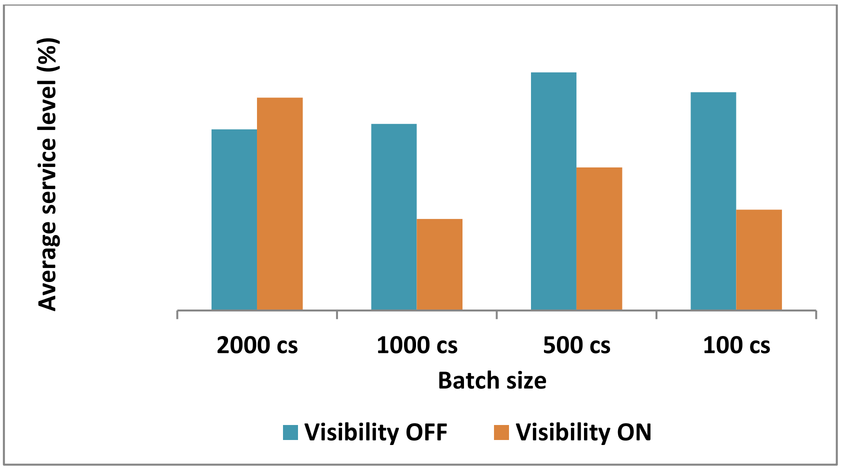

Figure 40: Batch size vs. SAMBC with increased visibility

Sharing and using POS-data throughout the supply chain has always been seen as the holy grail when it comes to supply chain optimization. Producing (or even mining) what is daily needed, is something that many companies pursue. Contrary to this belief, the experiments show that going down in production batch size, together with using POS-data (thereby going to a state where the manufacturer is producing what is needed) does not yield the desired service-levels. There is however hope for these people as the experiments are done with constant lead-times, safety-stocks and MOQs.

It can be concluded that there is a one main trade-off that needs to be made before using POS-data (if we take all other factors constant). Namely, whether to reduce the minimum production batch size or use POS-data in production and replenishment. Basically, this comes down to choosing between cutting out safety-margins (reducing the bullwhip effect) and moving to a pull supply chain all the way back to the production plant, or reducing inventory pile-ups (by decreasing the batch size) while maintaining a push supply chain until the warehouse of Procter & Gamble. In a later section, we will discuss this dilemma and the boundary conditions on whether to choose one or the other.

Connectivity

We have embodied connectivity in experiments where we had synchronized order & replenishment processes throughout the chain. Different degrees of connectivity were tested in two separate experiments:

1. Monday afternoon order release during promotions
2. Complete order & replenishment information process alignment

Because the first degree of connectivity is a specific problem for the Dreft ADW – Retailer X supply chain, we will only discuss the benefits of complete process alignment in this section.

It can be seen from the modeling results that completely synchronizing the order & replenishment information processes yields both better service level as well as an inventory reduction. For all different batch sizes, the overall gain in inventory was approximately 10%, while the absolute service level rose to ± 98.60% (shown in the graph below). These results can be explained by the fact that by synchronizing the timings in the supply chain of Dreft ADW, both uncertainty in demand and days coverage are reduced.

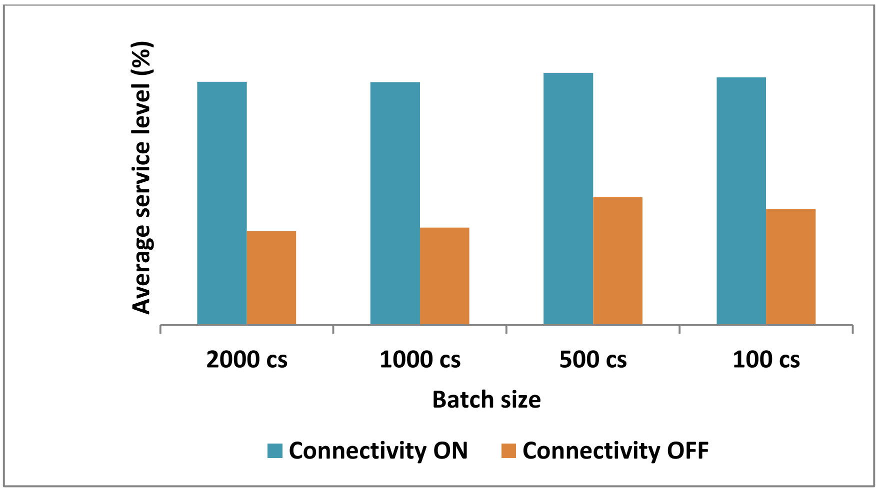

Figure 41: Batch size vs. SAMBC with increased connectivity

Just as for the conclusion on visibility, it needs to be mentioned that the there are some assumptions and case-specific variables that have a large influence on these numbers. The supply chain of Dreft ADW – Retailer X has very low lead-times. Stores and the Retailer X warehouse are replenished within the day, while replenishment of the Procter & Gamble DC only takes two days. This also explains why implementing this intervention would yield such high benefits. When a supply chain needs to cover two weeks of lead-time, the effect on inventory and service will be much less, since those few hours will not make a big difference.

Transparency

The final concept that was tested in the model was transparency. This was embodied by leveraging the information that Procter & Gamble has in their production process. The results of the modeling experiments demonstrate that the largest benefit is the reduction of inventory. It was shown that by using up-to-date information in the production process, inventory can be reduced by 15-20% with respect to the starting point. Looking at the graph below, it can be seen that increased transparency together with a smaller batch size yield the same pattern as without transparency. It must however be said that increasing transparency has the most effect on inventory when the batch size is large. This is of course easily explained by the fact that an overproduction of one batch of 2000 cases has much more impact on inventory than a single batch of 100 or 500 cases.

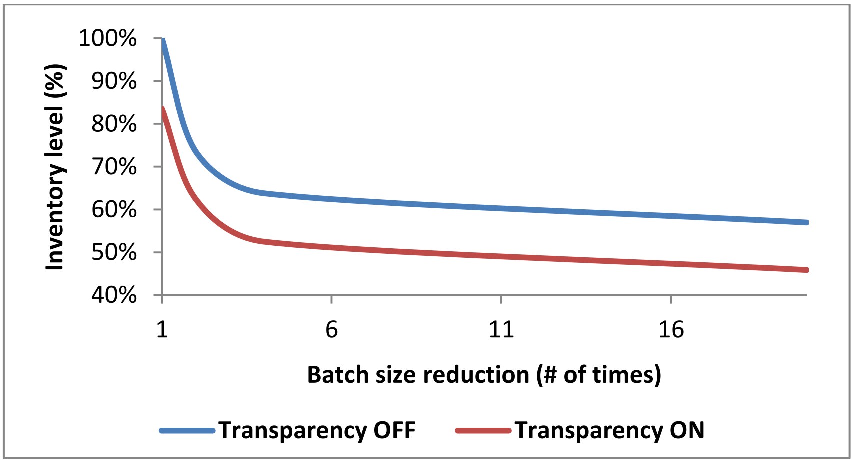

Figure 42: Batch reduction size vs. inventory with different levels of transparency

However in all these experiments it can be seen that this reduction in inventory will also diminish the service level. This can be explained in the same way as the (relative) lesser effect of transparency with a reduced batch size. Missing a production (or producing too late) with a smaller batch size would have a smaller impact on service than a large production batch.

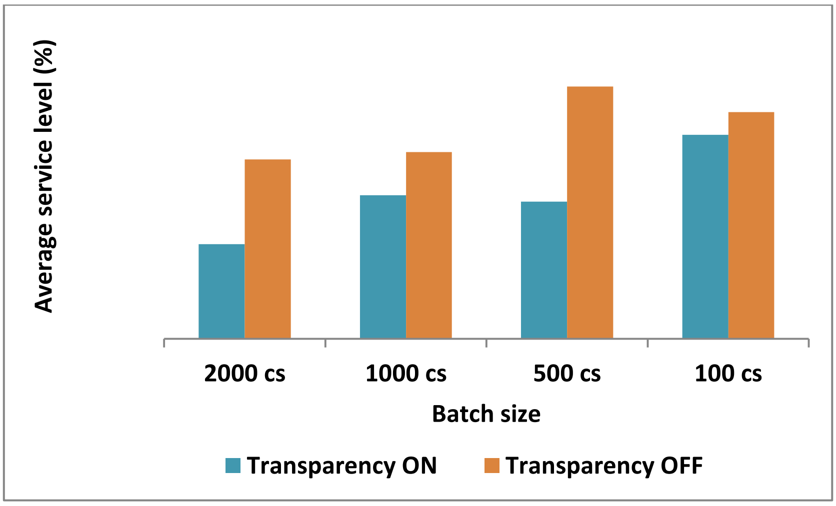

Figure 43: Batch size vs. SAMBC with increased transparency

For the supply chain of Dreft ADW, we can conclude that increasing transparency will decrease service level and lower inventory level regardless the choice of decreasing the batch size. The effect of increased transparency is however (generally) lower when batch sizes are smaller. This will therefore force Procter & Gamble to choose between one of these scenarios.

Combinations of Concepts

Now that we have discussed the different interventions with respect to each other, we will see if we can identify general trends of using combinations of interventions (apart from combinations with different batch sizes). It would be rather interesting to examine whether or not certain interventions would flourish or shrivel when combined with one another. In the next section, we will discuss the most interesting combinations.

Visibility and Connectivity

It can be extracted from the results that when looking at both service level and inventory level, visibility and transparency combined yield interesting (out of the ordinary) results. It can be seen that when implementing one of the two, inventory can be reduced with (for visibility) the downside of and thereby also lowering the service level. However, by combining the two, service levels can be increased while simultaneously decreasing inventory even more. In the table below these numbers are displayed for the various batch sizes:

Table 17: Effect of increased visibility and connectivity combined

		Visibility	Connectivity	Combined
2000	**Service (δ)**	0,16%	1,26%	**2,05%**
	Inventory (δ%)	-7%	-7%	**-13%**
1000	**Service (δ)**	-0,47%	1,23%	**1,65%**
	Inventory (δ%)	-8%	-10%	**-14%**
500	**Service (δ)**	-0,47%	1,05%	**1,48%**
	Inventory (δ%)	-8%	-8%	**-16%**
100	**Service (δ)**	-0,58%	1,11%	**1,20%**
	Inventory (δ%)	-10%	-11%	**-18%**

As we have already briefly explained, this observation could most probably be explained by the fact that both synchronizing the business processes around ordering and replenishment and implementing the use of POS-data will result in the following situation. Synchronizing the order processes will ensure that the supply chain replenishes daily what is sold, while using POS-data ensure that not too much is ordered. Combining these two interventions will results in both an increase in service as well as a reduction in inventory.

Visibility and Transparency

Combining visibility with transparency more or less yields the same results as combining visibility and connectivity. The effect of visibility we have already discussed in the previous section. Transparency, however, shows the same pattern; a decrease in inventory paired with a decrease in service. In this case, combining visibility and transparency is more about damage control than actual improvements.

Table 18:Effect of increased visibility and transparency combined

		Visibility	Transparency	Combined
2000	**Service (δ)**	0,16%	-0,33%	**0,28%**
	Inventory (δ%)	-7%	-16%	**-19%**
1000	**Service (δ)**	-0,47%	-0,17%	**-0,39%**
	Inventory (δ%)	-8%	-15%	**-19%**
500	**Service (δ)**	-0,47%	-0,45%	**-0,37%**
	Inventory (δ%)	-8%	-18%	**-20%**
100	**Service (δ)**	-0,58%	-0,09%	**-0,55%**
	Inventory (δ%)	-10%	-19%	**-23%**

As the table shows, service levels will still be lowered by implementing both visibility and transparency. The loss in service is however overall less when production uses up-to-date information when already using POS-data as their primary information input. In other words, when implementing the use of POS-data in the chain, one should also use this data in the production planning.

Visibility, Connectivity and Transparency

The last combination of concepts that we will look at is what happens when we are implementing all the different concepts. We have seen that combining visibility with respectively connectivity and transparency yields results that can be used in formulating a specific approach on how to improve the supply chain of Dreft ADW. Next, we will see whether a combination of all three concepts can provide even larger benefits.

In the table below, the single interventions (and their results) are shown, together with the results of all interventions combined. The table reveals that, when implementing all three concepts, both inventory can be reduced and service can be improved. It depends, however, on the production batch size what the overall size of the price will be (note here that inventory reduction by decreasing the batch size is not taken into account).

Table 19: Effect of increased visibility, connectivity and transparency combined

		Visibility	Connectivity	Transparency	Combined
2000	**Service (δ)**	0,16%	1,26%	-0,33%	**2,18%**
	Inventory (δ%)	-7%	-7%	-16%	**-20%**
1000	**Service (δ)**	-0,47%	1,23%	-0,17%	**1,91%**
	Inventory (δ%)	-8%	-10%	-15%	**-18%**
500	**Service (δ)**	-0,47%	1,05%	-0,45%	**0,84%**
	Inventory (δ%)	-8%	-8%	-18%	**-21%**
100	**Service (δ)**	-0,58%	1,11%	-0,09%	**0,51%**
	Inventory (δ%)	-10%	-11%	-19%	**-23%**

Comparing inventory reduction percentages shows that in each scenario the overall reduction is around 20% of the starting inventory. The real difference between the different batch sizes is in service. The increase in service level is 2.18% and 1.91% for a batch size of 2000 or 1000 cases respectively. For the smaller batch sizes, this increase is not more than 0.84%. One could therefore say that in the scenarios with larger batch sizes, the available inventory in the supply chain is best used, while in the other scenarios the inventory in the chain will get too low for the assumed lead-times and safety-stocks.

Sub-conclusion

All in all, these results show that Procter & Gamble will first need to make a decision on their production batch size policy, before choosing how to improve their supply chain with the use of the proposed interventions. In the next section we will describe the value (expressed in Euros) of implementing the various interventions in the supply chain of Dreft ADW for different batch sizes. With these calculations is should be possible to express the value of information in Euros.

9.3. Value of information

This section tries to determine the value of information in the supply chain of Dreft ADW. As the information in the previous section showed, information can be very valuable when used in the right context. Different batch sizes have different effects on the value of shared information, as the main driver behind cost (savings) is inventory. With a smaller batch size, the effect of the kind of information that is shared in this project varies. In this section, the tested interventions will be discussed to generate the perceived value of information.

Value of POS data (visibility)

In the previous section, it could be seen that the use of POS data can be very beneficial in the supply chain. This does, however depend, on the batch size that is used in the production plant. Both the use of POS data and the reduction of production batch size are measures to reduce the product inventory and therefore influence each other (and the subsequent value of the POS information).

In the figure below, the value of POS data with varying batch size is depicted. This value is calculated in the same way as the cost calculations on the effect of different batch sizes in section 9.1. The included costs and benefits are: changeover costs, inventory reduction and service impact.

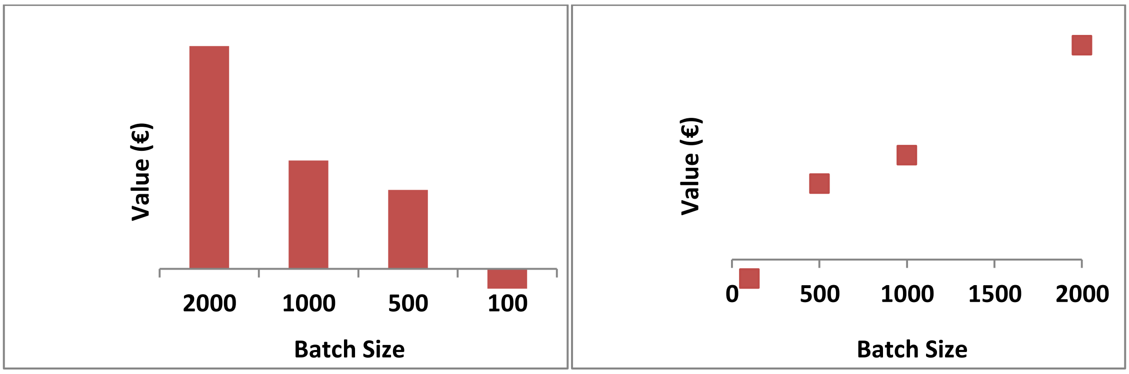

Figure 44: Value of POS data; the value of information is calculated in each scenario (shared POS data and varying batch size) with respect to the base experiment (no interventions) of a production batch size of 2000 cases.

It can clearly be seen from the graph that the value of POS data diminishes when the amount of inventory in the chain decreases (with smaller production batch sizes). This result is expected, because the main benefit of using POS data is the damping of the bullwhip effect. This also explains the behavior of the graph on the right, the value of POS data seems to increase linearly with increasing batch size. When there is already less inventory in the chain, the effect of using POS data will subsequently be less. One can think of scenarios that would contradict these findings (for example supply chains with very long lead-times), but in the case of Dreft ADW the value of POS data is in the hands of Procter & Gamble.

Value of order information sharing process alignment (connectivity)

The value of the on-time sharing of order and replenishment information is the second measure of vertical collaboration that was under investigation. The same calculations that have been done for measuring the value of POS data and batch size reduction, are performed to determine the value of aligning the order information sharing process.

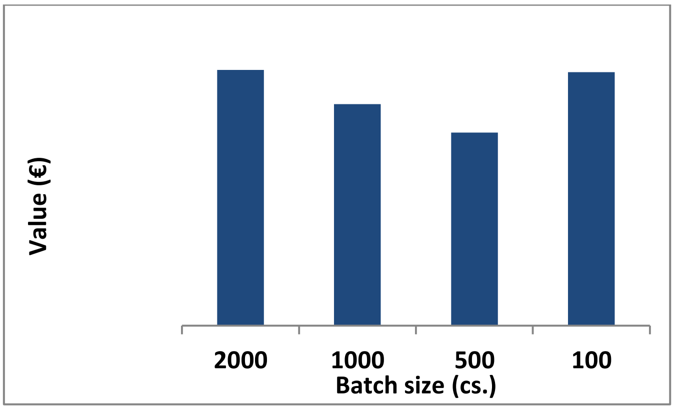

Figure 45: Value of order information sharing process alignment; the value of information is calculated in each scenario with respect to the base experiment (no interventions) of a production batch size of 2000 cases.

In contrast to having increased visibility, aligning the order information sharing process is not heavily dependent on the batch size. As the main driving forces behind the value are inventory reduction and induced changeover costs, it can be concluded that the overall inventory that will be removed from the supply chain of Dreft ADW when implementing this intervention is constant in absolute numbers. Thus, regardless of the choices that Procter & Gamble makes on batch size reduction, this intervention can add value of approximately.

Value of using up-to-date information in production planning (transparency)

The last intervention discussed here is again the value of using up-to-date information in production planning. The same calculations as in the previous sections are performed to determine the value of up-to-date information in production planning. These calculations yield the graphs depicted below.

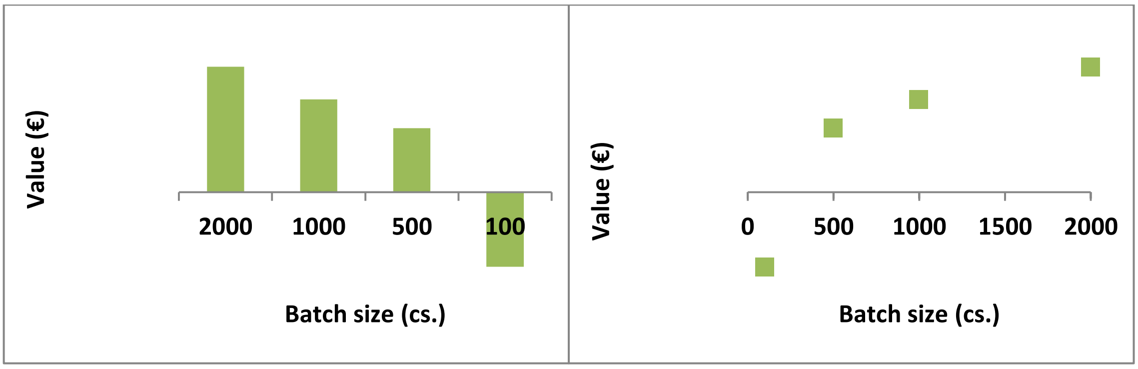

Figure 46: Value of up-to-date information in production planning; the value of information is calculated in each scenario with respect to the base experiment (no interventions) of a production batch size of 2000 cases.

As expected, the value of up-to-date information in production planning also decreases with reducing the batch size. A decreased batch size matches the order amounts of the retailer already quite well and it is in this case the non-linear increase in changeovers that will cause this reduction in value. The absolute reduction in inventory that can be achieved with this intervention is constant and will therefore not counteract the increased costs of changeovers.

This is being emphasized by the graph on the right. It seems that there is a limited amount of inventory reduction that can be achieved when implementing this intervention. When the batch size is increased to larger volumes (bigger than 2000 cases), the benefits of implementing this intervention will not increase. Just as the driving factor behind the costs (changeover costs) will have a minimum value (1 changeover in the year), resulting in the asymptote shown in the right graph.

9.4. Comparison with previous research

In the last section of this chapter, a comparison with previous research will be made. In the literature review in chapter 3, a specific section was devoted to the value of information in other research. The question thus arises, how does this research compare to previous investigations on value of information?

If one recalls the paper of Cachon & Fisher (Cachon & Fisher, 2000), they stated that information sharing could lower supply chain costs by 2.2% on average and can be as high as 12.1%. Comparing these numbers to the findings in this research, the maximum benefit that can be achieved in this research by sharing information (thus increased visibility) is approximately X€. Although total supply chain costs are not available for this research, it is possible to calculate the supply chain cost reduction for **only Procter & Gamble** supply chain costs. This would indicate that the total maximum supply chain costs can be reduced by 12.2% (when compared to the X€ of total supply chain costs), which remarkably closely resemble the maximum gains. It must however be said that our model suggest that a larger batch size would even yield higher gains, but on the other hand, this would also most probably result in higher supply chain costs for Procter & Gamble.

Looking at the findings on batch size reduction by Cachon & Fisher (2000), they stated that costs could be reduced by 22% when batch sizes are cut in half. In this research it was observed that dissecting the batch size resulted in X€ of profit, which is a cost reduction of 44%. Although these two do not match, this can probably be explained by the fact that the batch sizes of Procter & Gamble are already too large to begin with. Looking at the graphs on batch size reduction in section 9.1, it is expected that using a larger batch size will only increase inventory (and thus costs) and therefore the benefit will also be larger.

All in all, this research draws the same conclusion as Cachon & Fisher (2000); information technology should be used to align the flow of materials, rather than the flow of information. It can be seen that both process alignment as well as batch size reduction (or alignment to the retailer needs) deliver the best results and the biggest cost reduction.

Comparing the results of this research to those of Lee, So & Tang (2000), it can be stated that the same conclusions can be drawn. Although our focus was not on measuring the effect of high or low volatility in demand, the results of our research do provide an insight in this. It is not the low volatile regular sales that make the difference in the value of information sharing in the supply chain of Dreft ADW, but rather the highly volatile promotional weeks (Lee et al., 2000). It is the latter that make the difference in cost reduction, as up-to-date information in these weeks is vital for not over- or underproduction.

Gavirneni, Kapuscinski and Tayur (1999) was the last paper that was highlighted (Gavirneni et al., 1999). They came to three main conclusions: 1. savings increase with increased capacity (larger production quantities), 2. information is most beneficial at moderate values of end-item demand variance and 3. information is less beneficial for large minimum order quantities. When comparing these three conclusions to the outcomes of this research, it can be concluded that at one of the results matches.

Looking at the first conclusion by Gavirneni, Kapuscinski and Tayur, this research did not take capacity as a variable; the simulations in this research have all been run with infinite production capacities. Their second conclusion is in line with the observations by Lee, So & Tang and is discussed above. The last conclusion of Gavirneni, Kapuscinski and Tayur (increased MOQ of the retailer results in a lower value of information) is something that was not investigated in this research as Retailer X was not interested in these results.

It can be concluded that when compared to previous research, the results of this thesis project are in line with what is previously found. Next to that, this research presents new findings with respect to the value of information and value of material flow alignment.

10. Conclusions

This report ends with a conclusion on the effect of vertical collaboration in the supply chain of Dreft ADW. This is done by discussing the answers to the research sub questions and subsequently the main research question. Next to that, a short discussion is written on whether or not the deliverables of the project have been met.

10.1. Answers to the research (sub) question(s)

Looking back at the core research question, 6 sub questions had been defined that would help answer the main research question. The first sub question that we answered was:

1. What is the current flow of materials and information and what are the various stakeholders in the supply chain?

Through a supply chain mapping and a stakeholder analysis we were able answer this question in Chapters 4 to 6. The mapping of the stakeholders and the material and information flow can be found in Appendix C.

The second sub question was related to the performance of the supply chain and was phrased as:

2. How are the supply chain KPIs measured and what is their current state?

This question was answered in Chapter 5. The KPIs were defined as service, inventory and costs and were measured as follows:

Service:	$SAMBC\ \% = \frac{\sum missed\ cases}{\sum cases\ ordered}$	Current state: X%
Inventory:	$Days\ on\ Hand = \frac{Total\ Chain\ Inventory}{Sales\ per\ Day}$	Current state: X days
Costs:	Measured in Euro, but could not be measured due to the lack of data	

The third sub question required a generic approach, as it addressed the scientific explanation of collaboration in the supply chain:

3. How is collaboration in the supply chain defined?

This question is answered in Chapter 4, where an overview of the performed literature study was given. The study started out with a broad definition of collaboration and was then narrowed down in order to identify five elements required for optimal information sharing in vertical collaboration. These five elements were:

1. Visibility
2. Connectivity
3. Transparency
4. Synchronization
5. Willingness

Together these five elements comprise a list that help enabling vertical collaboration through information sharing. Next, they were used to help answer the next sub question:

4. <u>What are future scenarios with collaboration in the supply chain of Dreft ADW?</u>

We have answered this question by organizing a workshop with attendants of both Procter & Gamble and Retailer X. We were able to get various industry experts in a single room to assess the current state of the supply chain and brainstorm on a future with increased vertical collaboration. We have identified four different supply chain interventions that sketch different future scenarios with collaboration.

1. Order & replenishment information process alignment (connectivity)
2. Batch size reduction (connectivity)
3. Availability of real-time information (visibility)
4. Use of available up-to-date (SDF) information throughout the chain (transparency)

What these specific scenarios entail, is described at the end of Chapter 5. The next step was to determine (quantitatively) what their subsequent impact would be. The research objective stated that this would be done by computer modeling. To test these scenarios in a computer model, we first had to answer sub question 5:

5. <u>What software package/tool must be used to model the supply chain in?</u>

This sub question is answered in chapter 7. We have chosen to make an Agent-Based Model in the software package NetLogo 5.2. This choice of modeling technique was based on the fact that we faced a complex multi-agent problem with both technological and sociological aspects. Eventually it turned out that this was not really the case and that the model could have been built with other modeling techniques. However, the model did work and enabled us to answere sub question 6:

6. <u>What is the quantitative impact of these future scenarios on the supply chain KPI's of Dreft ADW?</u>

This is the last of the six sub questions and the most important one in answering our main research question. We have tested various possible (36) combinations of the, by sub question 4 mentioned, future scenarios. Chapters 8 and 9 extensively discuss the impact of the future scenarios, so here we will provide a summarized overview of the most important findings.

In chapter 5 we have sketched a pathway for the implementation of the different interventions based on the easiness of implementation. These four subsequent steps are depicted in the table below for the four different batch sizes that were under investigation. This table shows the cumulative values when the interventions are subsequently implemented in the supply chain.

It can be seen that the benefits, expressed in Euros, greatly differ per scenario. Moreover it can be extracted that a trade-off needs to be made between on the one hand batch size reduction and safety-margin cuts on the other. Recommendations on future steps are given in the next chapter.

Figure 47: Overview outcome experiments

With reference to this table, we will be able to answer the main research question.

"Could a vertical collaboration in the supply chain of Dreft ADW lead to better service, cost and cash results?"

The simple answer to this question is: yes it can. With the last sub question, we have showed that, without changing the world around the supply chain and only creating more vertical collaboration in the supply chain, both service and cash results can be improved. The size of the prize, however, depends on the choices Procter & Gamble wants (or is able) to make on the extent of vertical collaboration. In the next chapter we will discuss the trade-offs for Procter & Gamble.

10.2. Assessment of the deliverables

Next we will elaborate on the extent to which we have met the beforehand determined deliverables of the project. Below, the different deliverables are listed and discussed whether or not these have been met.

1. A model that uses collaboration in the supply chain of Dreft ADW to measure the impact of collaboration on supply chain KPIs → *This model has been designed and is operative*
2. Advice on practical improvements in the supply chain of Dreft ADW, based on various experiments → *this will be given in the next chapter*
3. A research report → *delivered*
4. Final presentation for the supervisors and others who are interested → *scheduled for 22^{nd} of January 2016*
5. Final presentation with supply chain recommendations for management of Procter & Gamble and Retailer X → *a presentation has been given to management of Procter & Gamble on 23^{rd} of November and some of the results have been shared with Retailer X*

11. Recommendations

In the final chapter of this report we will provide the reader with recommendations that follow from the research. The chapter discusses two kinds of recommendations. First we will focus on our advice to Procter & Gamble. What are the choices that Procter & Gamble needs to make when implementing the different interventions on the supply chain of Dreft ADW and what are the general learnings that they could apply to other supply chains? Secondly we will give some recommendations on future research.

11.1. Recommendations for Procter & Gamble

Our advice to Procter & Gamble is twofold. First we will give our view on which decisions to make when implementing the different supply chain interventions. After that we provide the general learnings that can be extracted from this case-study.

Implementation advice

We base our choices on the table shown in the conclusion when answering sub question 6. We would advise Procter & Gamble to perform the following steps on the Dreft ADW supply chain:

Short term (1-2 years):

- Reduce the batch size to 1000 cases: This would give a huge decrease in inventory, freeing up a lot of cash. The costs that come with the increased downtime due to more changeovers do not weigh up to the benefits of the decrease in inventory.
- Implement a Monday afternoon release during promotions: this would increase service, resulting both in cost benefits and creates goodwill at the customer.
- Use up-to date information in production planning: another great decrease in inventory resulting in cash benefits.

If these interventions would have been in place in the fiscal year 14/15 for the set of Dreft ADW SKUs in scope, the total benefit (expressed in euros) would have been approximately **€ X.-**. Comparing this to the total gross value of this set of Dreft ADW SKUs (X million euro), the benefit is approximately **X%**. The largest part of this benefit can be attributed to a decreased inventory, however it should not be disregarded that the intrinsic value of the increased service levels is also a very important benefit from these interventions.

Together these three interventions will account for the largest part of the benefits that can be obtained with the proposed interventions and are relatively easy to implement on the short term (this is emphasized by the fact that a pilot with a Monday afternoon release has already started). Looking at the long term (2-5 years from now)

Long term:

- The next step that should be taken is to research whether it is possible to reduce the minimum batch size to 500 cases or even smaller. This would again induce a decrease in the inventory level resulting in cash benefits. If Procter & Gamble gets to a point where this becomes interesting, we do recommend that the safety-stock policy gets re-evaluated in such a case.
- When it is possible to decrease the batch size it would be worth fully aligning the supply chain and subsequently begin to use POS-data as the primary trigger for replenishment.

These longer term recommendations are focused on creating a complete pull supply chain, where one produces daily what is required.

General Learnings

The general learnings of the project is that the provided supply chain interventions (based on vertical collaboration in the chain) are suitable for collaboration with 'advanced' customers on high volume (low-tech) products e.g.:

- Retailer X
- Retailer Y
- Retailer Z
- Home-care
- Fabric-care
- Baby-care

The current state supply chain of Dreft ADW data-analysis and computational modeling experiments also provided interesting insights that Procter & Gamble could extend to other supply chains.

In general, Procter & Gamble needs to leverage the information that is available. It was identified that even though up-to-date information on promotional forecasts was available, this was not used in the production schedule. This results in overproduction, which in turn leads to higher inventory costs. Procter & Gamble can take from this that they should examine the availability of data in other supply chains and see whether this is leveraged completely or not.

Next to that Procter & Gamble must reevaluate their minimum batch size. Previous research as well as the current research shows that reducing production batch size can be hugely beneficial. It must be noted that by reducing the minimum batch size does not immediately mean that every production run produces this amount. Therefore the changeover costs will not outweigh the inventory reduction benefits.

When opting for the use of POS data in replenishment planning, Procter & Gamble needs to ask themselves whether this is useful for the specific supply chain under investigation. POS-data can be very beneficial in supply chains with a highly volatile demand, but is less valuable in supply chains with a predictable demand. Next to that, this research shows that, if Procter & Gamble pursues the goal of decreasing their minimum batch size, the value of POS data decreases.

11.2. Recommendations for future research

The main goal of this research was to assess the value/effect of vertical collaboration in the two level supply chain of Procter & Gamble and Retailer X in the specific case of Dreft ADW. An agent based modeling tool was built to test the effects of certain components/applications of vertical collaboration. These components were mainly aimed at solving current day problems in the specific case of the supply chain of Dreft ADW. With the help of historical data and hypothetical re-runs (what would have happened if we had done this or that), it became possible to quantify the effects of certain applications of vertical collaboration.

During this study numerous uncertainties were encountered for which various assumptions and simplifications needed to be made. On top of that, due to the case specific nature of the research, different aspects of vertical collaboration in a supply chain were intentionally left out of scope. Besides the relevance in literature, the research also needed to be of added value for the problem owner of the research. Now the question arises: What would thus be the recommendations to any future researcher that wants to proceed on this work? We have devised a list of several recommendations for future research and separated them in different themes:

Vertical collaboration in the supply chain

1. We have mainly focused in this research on the sharing of (certain types of) information. Vertical collaboration entails much more than that. One could devise a same sort of research that takes into account other viewpoints on vertical collaboration.
2. In this research certain interventions to embody vertical collaboration were designed. These were based on case-specific problems and some were more often found in literature than others. This was just a small set of the various possible optimization interventions that come from vertical collaboration. It would be useful to design and test other supply chain improvements that come from vertical collaboration.

Agent Based Modeling recommendations

1. One of the problems encountered is the added value of ABM in (applied) supply chain research. It proved to be a suitable tool, but maybe too powerful for a case-study research like the one done in this project. One could assess the added value of ABM in this kinds of research.
2. Overall various assumptions are made in the model. In future research all these assumptions could be better evaluated on their validity.
3. Future research could adapt the current model to assess other supply chains than the supply chain of Dreft ADW, making the model more generalizable.
4. Instead of being focused on the past (what would have happened if we had done….), one could use the current model to be more forward looking. Use in-depth scenario analysis to devise plans for the future and run the model accordingly.
5. The current model does not fully leverage the abilities of ABM. No actual negotiations take place during the process, only predetermined order and replenishment procedures. One could expand the model with increased negotiations or in-game cost-benefit trade-offs.
6. Interesting would also be to test the model with high volatility during regular weeks. In the current research it was less interesting for Procter & Gamble and therefore not included.
7. It is suggested that a thorough sensitivity analysis is done on the model. Although the data was available, there was not enough time to perform a thorough analysis.

12. Reflection

In the very last chapter of this report, I will give a reflection on my 7 month period of research, in which I performed this master thesis project. In this chapter a reflection is written for each major activity that passed the revue in this thesis project. Next to that I will reflect on my time at Procter & Gamble instead of choosing to graduate at the university.

12.1. Research proposal

When I started this project, I had limited to no background in supply chain management, nor in agent-based modeling. My Bachelor degree was in Molecular Science & Technology and Management of Technology was part of a double-degree program together with the master Chemical Engineering. An easy choice would have been to take a subject that was inside my comfort zone (more chemically oriented), but although I did not have a background in supply chain management and engineering I had always found it a very interesting field of research. Supply chain management incorporates both the sociological as well as the technical aspects within a (high-tech) company and it was this element that made me want to perform a master thesis research in this scientific field.

What I might have misjudged was the extra work-load that it took to catch up on the "basics" of supply chain management. It was necessary for me to first gain a better grasp of what supply chain management really incorporated before I could start writing a research proposal. Luckily Procter & Gamble provided me an already better delineated project in the field of supply chain management; collaboration in the supply chain. This is however (as is showed in the literature study) quite a broad concept, so for my research proposal I needed to scope the project even better.

My kick-off meeting (and subsequent agreement on my research proposal by everyone involved) was only after being 3 months into the project. This is something that raises an eyebrow, as the actual time that is designated for a master thesis is about 5 months. I think it is safe to say that both the limited knowledge on supply chain management as well as my problems with delineating and scoping a project have caused this delay. I do, however, not feel that this was a waste of my time. Taking your time to find the right project (that you are excited about) and scoping the project in the right way will definitely improve both your mood throughout the project and it will definitely safe you time at the end. The dive into the field of supply chain management also gave me a broader view on what the business world had to offer besides chemistry or process engineering. Next to that the process of writing a this research proposal definitely learned me a lesson on scoping of a project.

When I review my kick-off document now, I definitely think that I could have done better. Both on what to include and what not (I had the tendency to put many things on my "to-do list" while I already felt that those would probably not happen). This might have created some false expectations of what I would deliver in the end.

12.2. Literature study

The literature study is always a long and slow process within a master thesis, in which it always feels like you do not proceed or achieve anything. However, in my case it was a bit different. My 'literature study' started with finding out what the very basics of supply chain management were. In the first few months I started out with learning what FIFO means, what produce-to-demand entails or even learning that warehouse in Dutch "toch echt niet 'warenhuis' is". By reading papers and presentations on these basic concepts I really had the feeling that I was learning something. Next to that I had already written a master thesis (for Chemical Engineering), so I knew what performing a literature study would entail.

Reflecting on the content of the literature study, it could have been more elaborate and have (a little) more depth. Especially I could have put more effort in searching for literature on the value of information and other projects that focused on researching the effect of vertical collaboration with the help of computational models. Because I was too focused on the combination of ABM with vertical collaboration in the supply chain, I forgot to extensively look at the projects that might have researched the same subject with other computational models. If I had done this, it might have helped me in two ways: 1. getting a better (upfront) understanding of what data I wanted to get out of my modeling and 2. figuring out what the limitations of other models were (apart from what is written in ABM literature) and where I could leverage the use of ABM in my research. I think that throughout the research I was more focused on my specific case-study on Dreft ADW and retrieving the data that was interesting for Procter & Gamble. Together with the fact that it had taken some time for me to catch up on the supply chain basics, this might have caused that I did not fully take my time to provide an elaborate scientific basis.

12.3. Dreft ADW supply chain analysis phase

The analysis phase of the current Dreft ADW supply chain consisted of a data analysis on inventory levels, service levels, shipments and production schedules. This was mainly done to examine where the current pain points are in the Dreft ADW supply chain.

Concerning the data analysis, I did not have much problems with this specific part. I performed this analysis alongside my literature study and writing a research proposal. Procter & Gamble did not provide me with a concrete research problem, which I therefore partly needed to find by performing this data analysis. Although I had multiple gigabytes of excel data-sheets (which have improved my Microsoft Excel skills dramatically), I was able to rather quickly and precisely digest this data and tie the different datasets together. It must be said here that this task would have been a lot harder when I was not able to retrieve this data from the stakeholders involved (therefore a big thanks to both Procter & Gamble and Retailer X).

Although the data analysis did provide me with the actual problems that were currently present in the supply chain, it might have also limited my experimental research. Where I now generated solutions on paper and tested the effect in a computer model, it might have been more interesting to do this the other way around; let the model generate solutions for the problems.

12.4. Supply chain model design

My design phase started with a detailed stakeholder analysis. Getting to know who is responsible for what and see how everyone influences the supply chain. The stakeholder analysis was a long and slow process where I needed to talk to various people within various companies, departments and offices (and even countries). This made the project of course very attractive and fun, but it also made it a little harder to talk to everyone. It really helped that in my ‘onboarding program’, the meetings with many of these stakeholders were already scheduled. So even before I knew which stakeholders I needed to talk to, I already got to know so many people that it helped me in a later stage of the project. All in all, the stakeholder analysis provided me with the right data and information on the actions of the various stakeholders that I was able to build a working computer model.

I think that the level of detail in my stakeholder analysis was quite ok. Translating the actions of the various stakeholders into one design, again scoping and knowing what to incorporate and leave out of the design was a difficult task. On the one hand I wanted to model the supply chain of Dreft ADW and therefore incorporate case-specific details. On the other I wanted to make a general model that might be useful for other supply chains and companies. In the end I think that I found the golden mean, with a model that is applicable to other products (a little more general than this specific case) as well as a model that could answer the questions of the specific case (thereby interesting for Procter & Gamble).

12.5. Modeling and the model

Because my background is not in supply chain management, I needed to leverage other applicable strengths. I therefore quickly noticed at the beginning of the project that one of my strengths would lie in making a computer model to measure KPIs of a supply chain. My programming knowledge was mainly in Matlab and not at all in Netlogo. I did, however, know computer language and was therefore quite certain that I was up for the task. With the help of some of my study friends, online lectures and the relevant study materials I quickly gained the needed knowledge on ABM and programming in Netlogo.

All in all I really enjoyed the programming part of my thesis. Transforming real-life problems into a working computer model that seems to actually generate the results that one wants or expects to see was very fulfilling. Although my lack of knowledge in ABM, I was able to make a computer model that yielded interesting results. It is however also this lack of knowledge that has resulted in a model that not fully leverages the opportunities of modeling with ABM. A more elaborate reflection is already incorporated at the end of chapter 8.

On a more critical note, I think that the resulting model is not more than a tool to test interventions that were identified by a data analysis. Although I am satisfied by what the model can do and the insights it has generated for Procter & Gamble, it might have been more interesting to focus less on the computational part and more on the implementation of the proposed interventions. A model is often made to create support within a company to apply improvements or induce changes. This support however was already available within Procter & Gamble. On the other hand, the outcomes of the model did provide Procter & Gamble with the needed data to further expand the collaboration activities with Retailer X.

12.6. Experimentation

Where one would normally generate and observe emergent behavior in an agent-based model, in this research the focus was on measuring effects of certain interventions (based on vertical collaboration) that would (maybe) solve the problems that were present in the case study (the supply chain of Dreft ADW). These interventions provided me with a clear experimental design, in which I could measure the effect of each intervention alone, or in combination with (an)other(s).

The results that I obtained from these experiments were often in line with what I expected. As stated earlier, there was an absence of complex emergent patterns and thus the behavior of the model was quite straightforward. This indicates that a simpler and less complex modeling tool would have sufficed. However the benefit of using ABM (and Netlogo for that matter) is that it is easy to understand and it is less of a 'black box' model. It was therefore more easily understandable than a model in for example Matlab that would have used complex formulas to calculate safety stocks etcetera. Also more in this can be found in the reflection on the performance of the model at the end of chapter 8. All in all the results were quite interesting for Procter & Gamble and, although maybe less scientifically relevant, the model experimentation results did provoke a change in the current supply chain practices at Procter & Gamble.

I think that having performed the same kind of study at the university and not on a case-study at a company, might have changed the outcomes of the experiments. In such a setting I could have given the agents in the supply chain more motion space and emergent behavior might have surfaced. Now there was little to no room for negotiations and it was either: “yes we are aligning our processes” or “no we will not do this”. Agent-based modeling is a very powerful tool, but might not be very useful in a case-study like the one in this research.

12.7. Graduating at Procter & Gamble

One of the (few) things I knew when I was looking for a thesis research topic, was that I wanted to perform the research at a company and if possible a large international company. Having already performed a master thesis research at the university I knew what its pros and cons were and because I did not have any experience in the “real world” it was actually quite an important factor to me that this thesis research was at a company. Luckily Procter & Gamble saw (although the lack of knowledge in the field of supply chain management) the potential that I had and offered me a graduation internship, for which I am still very grateful! I will not provide a broad disquisition between graduating at the university and at a company, but I will rather focus on my time at Procter & Gamble.

When I first joined Procter & Gamble my daily supervisor (Yannick) was still on a holiday, but his absence was very well covered by all the other employees from the SNO department. They made me feel at ease from the moment I walked in the office. I can honestly say that I very much enjoyed working at the office and although my work was very much a one-man project (especially the modeling part), everyone always offered to help me if and where necessary.

I think that graduating at a company did provide me a project that was very pragmatic and focused on actual implementation. This might have resulted in a less scientific thesis, but it did give me a sense of my research being useful. Next to that graduating at a company gave me a valuable lesson on how things work in the real world; having meetings (and a lot of them), setting clear deadlines and goals, communicating your progress and creating engagement from others to get things done.

All in all I had a great time working at Procter & Gamble and I have the feeling that I really helped them in improving their current supply chain practices. Whether they will use the model that I build again, is something that will remain uncertain. Although the model is quite easy to understand and Netlogo is a syntax that is easy learn, it will still take a substantial amount of time from one person to fully understand the workings of the model.

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Appendix A: The Physical Internet

Defined as: "*A global logistics system based on the physical, digital and operational interconnectivity enabled by smart modular containers, interfaces and protocols for increased efficiency and sustainability",* the Physical Internet (PI) can be envisioned as the Holy Grail in freight transport (Ballot et al., 2014; Montreuil, 2011). Introducing the concept should result in lower inventory costs, lower transportation costs (reduced down time, lower delivery lead times), increased service levels and reduce chances of out of stocks. To get there however the industry has still a long way to go. To better understand the concept, here is an example that compares the current day supply chain practices with the logistics in the future with the Physical Internet.

Imagine a truckload needs to be shipped from the Rumst warehouse of Procter & Gamble to a warehouse in Eastern Europe, say Bucharest. Nowadays this truckload would most probably be shipped by (1) a single driver/truck combination with a multi-day trip, (2) driving all the way while sleeping in their home away from home, and (3) once the delivery is done the driver picks up another (close by) delivery that needs to be returned to Rumst.

With the Physical Internet in place, this way of transport would be highly exceptional. The delivery would probably unfold more likely as follows. A first driver/truck will drive the first 2-6 hours of the journey, after which he will deposit the trailer for further transport at a "PI-hub" and return with another trailer destined for Rumst. A second driver/truck duo will soon afterwards pick up the trailer destined for Bucharest and drive to a second PI-hub. This will then be an iterative process until the trailer reaches the end point.

Figure 48: Example of the working of the Physical Internet (Montreuil, 2011)

Figure 48 shows the shipment process of both the current and PI logistics, with fictive PI-hubs along the way to Bucharest. One should note here that with the Physical Internet in place, delivery lead times can be dramatically reduced resulting in the various benefits described above. In the example given here, the total trip time of a container of goods is reduced by almost 43%. Next to that, the average driving time of truck drivers is 10 hours, which results in more drivers sleeping in their own bed at night and reduce the resting time of drivers while on the job. All in all promising prospects, but there are downsides and limitations to the concept.

However, if the PI would ever be introduced on a global scale there will need to be some changes in the current way of logistics thinking. The Physical Internet vision can be defined in thirteen characteristics:

1. Encapsulate merchandises in world-standard smart green modular containers.
2. Aiming toward universal interconnectivity.
3. Evolve from material to PI-container handling and storage systems.
4. Exploit smart networked containers embedding smart objects.
5. Evolve from point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport.
6. Embrace a unified multi-tier conceptual framework.
7. Activate and exploit Open Global Supply Web.
8. Design products fitting containers with minimal space waste.
9. Minimize physical moves and storages by digitally transmitting knowledge and materializing objects as locally as possible.
10. Deploy open performance monitoring and capability certifications.
11. Prioritize webbed reliability and resilience of networks.
12. Simulate business model innovation.
13. Enable open infrastructure innovation.

These thirteen characteristics can be grouped into 7 key points that differentiate the Physical internet with current logistics. These are summed up in Table 20 below.

Table 20: key points in differentiating between current logistics and the Physical Internet (Ballot et al., 2014)

Function	Current logistics	Physical Internet
Shipping	Goods	(standardized) Containers
Network	Specific services	Network of open and shared networks
Trip	Logistics service	Dynamic routing
Information system	Proprietary	Internet of things
Standard	Proliferation of standards	Market movement to agreement on interfaces, identification and protocols
Storage	Time-intensive (centralized)	Deployment logic
Capacity management	Private	Market-based

On a conference early 2015 in Amsterdam by ALICE (Alliance for Logistics Innovation through Collaboration in Europe), a roadmap was established for the introduction of the Physical Internet by 2050. This roadmap identified the intermediate steps that needed to be implemented at certain points in time, to enable the Physical Internet to be in place by 2050. Figure 49 below shows this roadmap; the intermediate steps and their delivery dates.

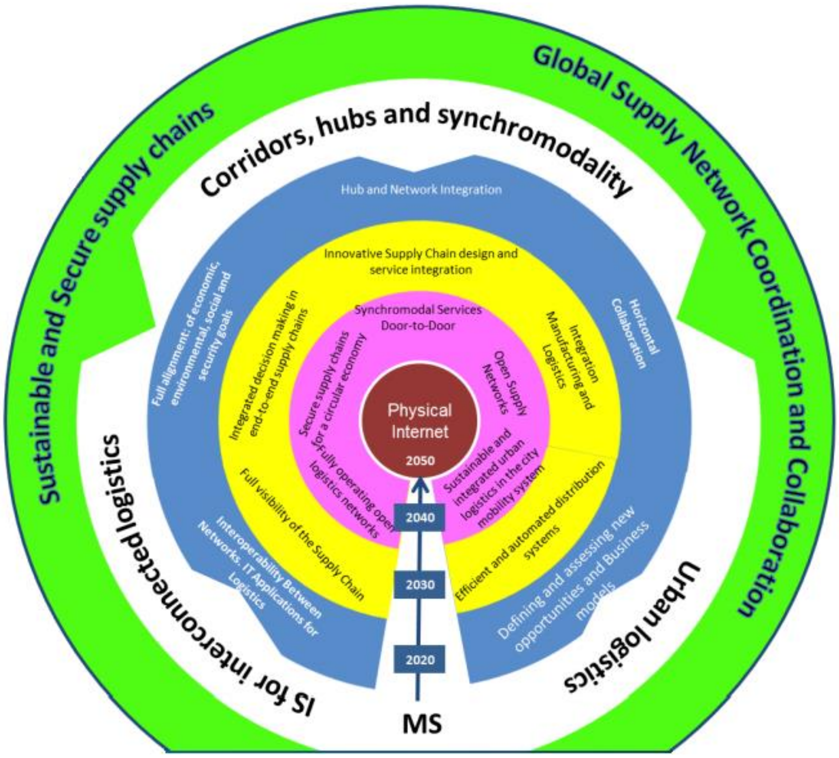

Figure 49: Roadmap to a Physical Internet in 2050 (Ballot, 2015)

Appendix B: Operations Research Methodology

The Operations Research methodology as defined op Eisselt & Sandblom is a process that consists of eight subsequent steps. These steps are given and defined in the figure below.

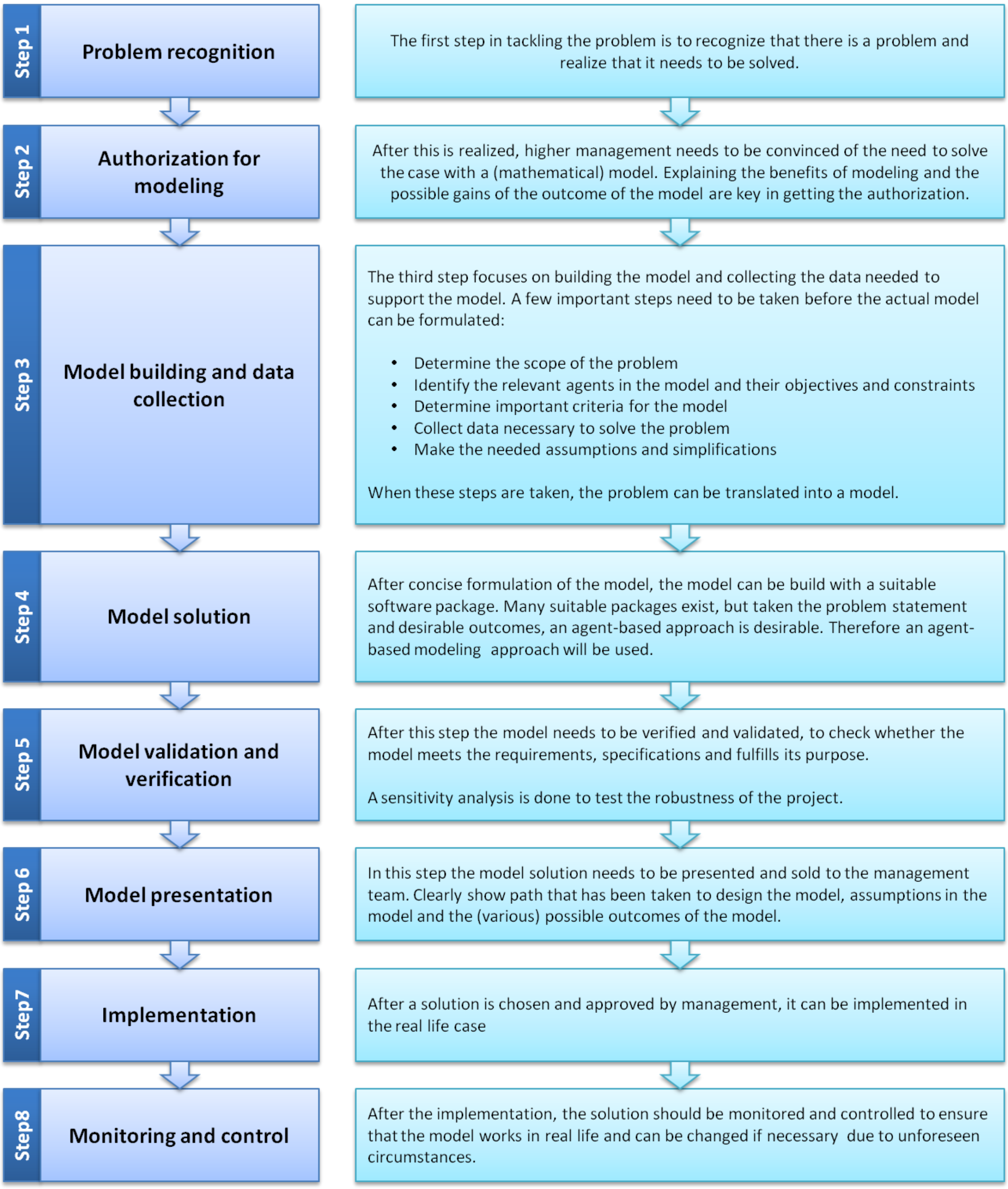

Figure 50: Operations Research Methodology

Operations research methodology for the service problem

As shown in Figure 50, the general method consists of eight steps. At Procter and Gamble steps 1 and 2 are already taken; the problem is recognized and authorization is given to produce a model to identify the potential benefits of a redesigned supply chain. Furthermore steps 7 and 8 will be out of the scope of this project, as it will be a feasibility study.

Step 3 to 6 of the Operations Research methodology for the SAMBC problem will look as follows.

Step		Description
Step 3	**Model building and data collection**	The third step in the Operations Research methodology, applied to the Dreft ADW service level problem, consists of a few different components. *Determine the objective for the service level problem* A mapping of the supply chain will identify the pain points in the chain with respect to the low service levels of Dreft ADW. A stakeholder analysis will determine the important players that need to be taken into account in finding solutions to the problem. The constraints and objectives of the stakeholders are translated into a combined and overall objective of the project. *Identify the important criteria for the model* When the objective is determined, the important criteria that need to be taken into account for the (to be modeled) solution must be identified. A combination of the constraints, objectives and pain points in the supply chain will result in criteria that provide the input for possible solutions to the problem that need to be evaluated in the model. *Collect the necessary data* While performing the previous analytical steps; data will be collected to help solve the problem at hand. The following data is required: • Flow and process handling steps of Dreft ADW materials and information • Inventory levels of finished products at manufacturer and customer • Shipments of Dreft ADW throughout the chain • Historical forecast, sales and service levels • Supply chain cost data and inventory costs • Lead times, production batch sizes, MOQ's, order frequencies etc. Based on this data a solution is modeled for the formulated problem statement. *Formulate the model* When the problem statement and question are formulated, they need to be translated in a way that can be modeled and used in Step 4.
Step 4	**Model solution**	In this step a suitable software package is chosen to build the model in. It is chosen to model the problem using agent-based modeling. With the developed model the formulated possible future scenarios will be tested and evaluated.
Step 5	**Model validation and verification**	In Step 5, the model is verified and validated by Procter & Gamble.
Step 6	**Model presentation**	In the last step the findings of the various experiments that are performed using the model will be presented to the management of both Procter & Gamble and Albert Heijn.

Figure 51: Operations Methodology Case Study Dreft ADW

Appendix C: Scenario Analysis

C.1 Introduction

Procter & Gamble have stated that they see the future as a fully synchronized end-to-end supply chain. This means that they desire a fully cooperating supply chain, including the customer (Retailer X) and their raw material supplier, to reduce the bullwhip effect throughout the supply chain. Reducing the inventory by introducing the just in time principle to (all of) their processes are in their opinion key to getting a competitive advantage over rivaling FMCG companies like Unilever and Henkel.

However one of the questions one can ask about this strategy is the durability of this system. Is this really such a good operating strategy in the future, or will there be such radical changes in the industry (due to external factors) that such a supply chain is not desirable and vertical collaboration is not the way to go? To take these possible changes in the industry into account, a scenario analysis is done on the subject.

The basis of this scenario analysis is a trend analysis in the fast moving consumer goods industry. Taking into account the doubts stated above, the main question of the scenario analysis will be: how do future developments influence the Procter & Gamble supply chain? As the supply chain that will be investigated is for Dreft Automatic Dishwashing products, a future scenario is sketched for the year 2030. This ensures that the consumer is at least one generation of dishwashers further on, but not too far in the future that radical changes in the dishwashing technology make the Dreft products obsolete (so the basis of the supply chain will be the same).

To decide whether or not the desired state of the supply chain holds in the future, various scenarios are sketched. This is done by identifying (mega) trends in the world, FMCG industry and supply chain management and their driving forces. These driving forces influence external factors that will have an impact on the supply chain of Procter & Gamble in the future. In the table below, the external factors, the impact they have on the supply chain and their driving forces are given. The factors that have a (large) impact on the supply chain are then described in more detail.

Table 21: Driving forces behind external factors

External Factor	Impact on SC	Driving force
Rise of the "Physical Internet"	+	Collaboration between companies
Continuous real-time control of flow of goods	+	Collaboration between companies
Continuous real-time control of flow of information	+	Collaboration between companies
Demand for on-shelf availability	+	Focus on customer/consumer service
Customized demand	+/0	Mass customization (BYOD)
Rise of local food markets	-	Increase in local buying

Rise of cradle-to-cradle	+/0	Going green/healthy living
Speed of delivery	+	Focus on customer/consumer service
Diminishing individual mobility	+/0	Scarcity of energy resources
Ageing world population	-	Low birth rate
Urbanization	+/0	Higher rate of succes in life in urban areas
Increase in e-commerce	+	Adaptation of consumers to online ordering
Big-data analysis	+	Computing power & availability of data
Limited use of dishwasher	-	Water shortage
No packaging	+	(Environmental) Costs of packaging
Rise in demand of high value-low cost products	+/0	Low economic growth
Need for high value goods	+/0	High economic growth
Costs of truck transportation	+	Rising oil prices
Larger means of transport	+	Rising oil prices
Shift in modes of transport	+	Legislation and oil price
Political developments in crises like: Russian-Ukraine, Islamic State/war on terror	-	Stability of geopolitics in these regions
Development of new ways of dishwashing	-	Developments in the dishwashing technology
Rise of the electric car/truck	+	Developments in the electric car technology
Increase in robotic use	0/-	Robotic technology developments

- Rise of the physical internet: the physical internet is an idea of manufacturers in the FMCG to share warehouse capacity with both their customers, other suppliers of their customers and ultimately their rivals. It is based on the current path of emails that flow from hub to hub to their end receiver. Here the path is dependent on the capacity of all the hubs in the world which are used by various email software companies.
- Continuous real-time control of flow of goods: this speaks for itself; if a product needs to be produced, transported to the warehouse or to the store, lead times are minimized and there is practically no delay in execution.
- Continuous real-time control of flow of information: this means that there is transparency in the supply chain between the various actors.
- Demand for on-shelf availability: people are more and more disappointed if a product is not on the shelf or if lead times of deliveries increase because the product is not in store.
- Customized demand: people become more accustomed to the fact that they are provided in every need. Customized demand thus entails the adaptation of goods for each individual customer.
- Speed of delivery: lead times of (on-line) ordering have become increasingly important and have dropped dramatically over the last years.
- Increase in e-commerce: online ordering of consumers has become embedded in current society and might increase even more over the coming years.
- Big-data analysis: due to the increased availability and accessibility of information, big-data analysis might become an important factor in forecasting sales in the FMCG industry.
- No packaging: because of the increased emphasis on green living, reducing packaging has become increasingly important.
- Costs of truck transportation: are driven by the oil price and legislation.
- Larger means of transport: also driven by the oil price.
- Shift in modes of transport: due to legislation on CO_2 emission and rising oil prices, a shift in the modes of transport is visible.
- Rise of the electric car/truck: going green, reducing CO_2 emissions and rising oil prices all contribute to the technological development of the electric car. Key here is the further development of the product and the adaption by consumers and industry in the upcoming 15 years.

Not all of the driving forces behind these external factors are relevant for this study and are therefore classified on uncertainty and impact. The table below divides these driving forces into four groups and driving forces that are both high on uncertainty and impact will become the main driving forces in the scenario analyses.

Table 22: Classification of diving forces on uncertainty and impact

		Uncertainty: Low	Uncertainty: High
Impact	Low	- Global/EU Politics - Low birth rate - Higher rate of succes in life in urban areas - Economic developments	- Increase in local buying - Developments in the dishwashing technology - Robotic technology developments - Water shortage - Going green/healthy living
Impact	High	- Focus on customer/consumer service - Developments in electric car technology - Adaptation of consumers to online ordering - Computing power & availability of data	- Collaboration between companies - Mass customization (BYOD) - Oil prices - Scarcity of energy resources

As one can see, there are eight major driving forces that might have a large impact on the supply chain if they push through. These eight driving forces can be named into three axes that form the scenario space:

- Technological progress – along this axis the technological progress in the field of FMCG and supply chain management. This entails the driving forces: *developments in the electric car, online ordering and computing power & availability of data.* One end represent a flourishing technology industry, where the sky is (not even) the limit; called the technological heydays. The other end is a world where there is a complete halt in the technological progress; the technological halt.
- Oil price – this axis represents the impact the oil price will have on the sketched scenario. Looking at the driving forces in the table above, it not only entails the oil price itself as a driver, but it is also a measure for macro-economic conditions and scarcity of energy resources. One end of the axis represents a scenario where oil is extremely costly (more than 1000$ per barrel) and the other end represents a scenario where oil has become extremely cheap.
- Collaboration in the supply chain – this axis entails, as the name states, the collaboration between companies. This is both inter- and intra-supply chain related. At one end, called collectivism, companies give high priority to working together with customers, suppliers and other companies that can benefit from collaboration. The other end is called individualism; companies only focus mainly on their own business (and in this case part of the supply chain) and no collaboration exists.

Combining these three axis give the scenario space, this is given in the figure below. Choosing a spot on this 3-dimensional space will give a scenario that uses an end of each axis to sketch the future in 2030. From this scenario space eight different scenarios can be formed. Looking more closely, from these eight scenarios only three seem likely and do not have inherent contradictions. For example, a scenario where a complete technological halt is coupled with extremely costly oil and individualistic companies is highly unlike. Other examples can be given and only three seem likely to happen and will be described in more detail.

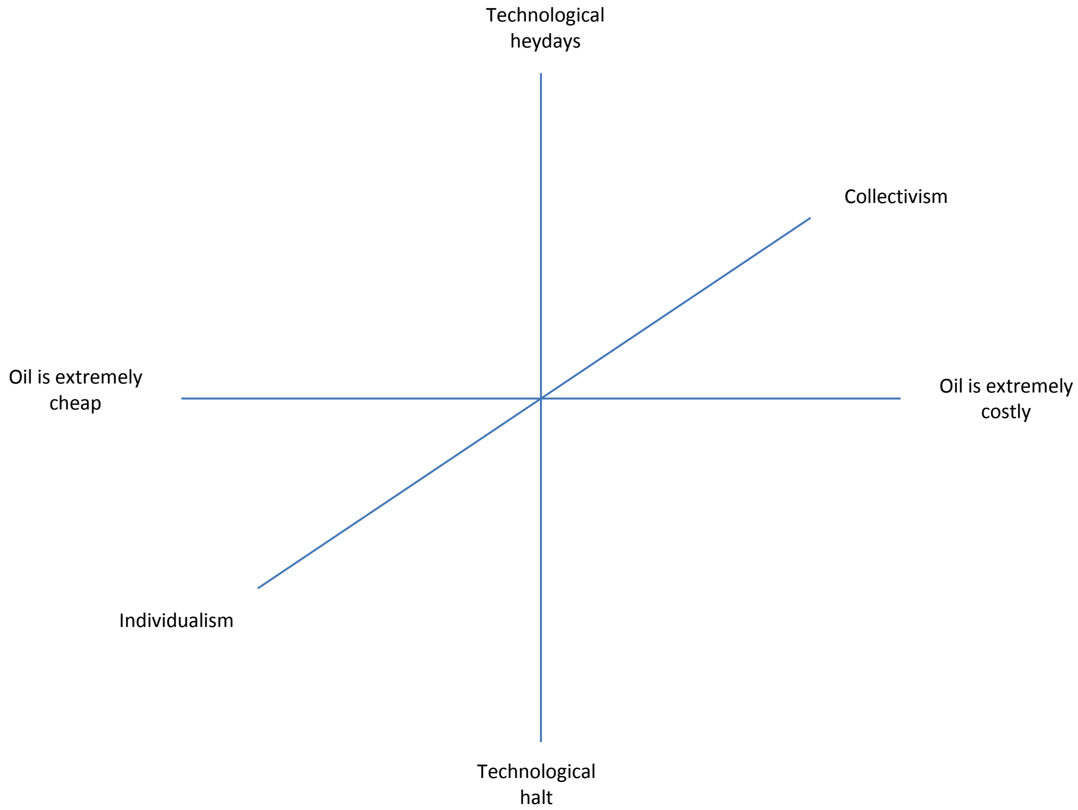

Figure 52: Scenario space

C.2 Scenario 1: "The Sky is the Limit"

This is a scenario where everything is good, after the harsh 2010's everything went downhill in the next decade. The scenario is sketched in at the ends of technological heyday, cheap oil and collectivism.

The technology sector is flourishing; the electric car has become fully adopted in everyday life and has the same standards as the gasoline car in 2015, with electric trucks becoming the primary mode of transport in the freight industry. Next to that the rise of the computer has pushed trough and the world is clearly in the digital age. At least 50% of all people order their products online and big-data analysis has become a key instrument in marketing, forecasting and information sharing.

Due to the great decrease in oil usage (by the car and freight industry) and improvements in oil refinery technologies, the price of a barrel of oil has dropped immensely. With an almost direct link to the macro economy the low oil price triggered economic growth throughout the whole world, again boosting technological improvements. Due to the large decrease in oil usage no real emphasis is put on decreasing CO_2 emissions; high CO_2 emissions is only frowned upon but is free of charge.

The overall vibe of positivity also penetrated companies in the FMCG industry, creating an optimistic view of the future. People trust each other and everyone grants each other a piece of the cake. This has resulted in a high degree of collaboration between companies. Even the largest competitors in the current day (Unilever and Procter & Gamble) have put aside their differences and are collaborating in the supply chain through shared warehouses and transportation for their products. In combination with the flourishing technology sector, complete transparency of practices and sharing of information has become an integrated part in many inter and intra company processes. Sharing and analyzing large amounts of information is possible because of the increased computing power and the development of predictive and modeling software.

The impact that these transitions have on the supply chain of Procter & Gamble are significant. A few examples are given below:

- Due to the adoption of the electric car and the developments in this technology, small trucks running on electricity can shuttle between warehouses, stores, plants etc.
- New technologies reduce changeover times and costs within the manufacturing plant.
- Due to the low oil price, large trucks are still used for large volumes and large distances. On top of that running with half-empty trucks still does not cost that much due to cheap gasoline.
- Big-data analysis is used to forecast sales and have personal targeted marketing. Forecast has only a very small error, due to the increase in computing power. This is due to the fact that many more different factors can be taken into account when making the forecast. Think of sudden weather changes, increase in sales of other materials, certain large events that take place etcetera. Accessibility of information also plays an important role in big-data analysis.
- Due to the technological development and adoption of e-commerce by the consumers, most of the consumers order their products for the larger part online. Next to that has the economic growth resulted in longer working hours, resulting in a boost for the convenience of online ordering.
- The rise of e-commerce has resulted in demanding consumers, who want to have incredibly short delivery lead times.
- Mutual trust between companies has changed the FMCG industry. Completely synchronized supply chains, where horizontal integration of suppliers, manufacturers and retailers to create a supply chain that can be seen as one, have emerged and are the new standard. Next to that the companies have gone one step further and vertical integration between suppliers, manufacturers and retailers has occurred. Warehouses are shared and transportation is not limited to the products of one supplier or manufacturer.
- Due to the mutual trust, sharing of information has become the new standard, as opposed to keeping information and knowledge within the company.

C.3 Scenario 2: “Back to the dark-ages”

This is a complete opposite of scenario 1; the financial crisis has escalated, Greece left the Euro zone and subsequently the European Union. This created a shock on a macro –economic scale that resulted in a depression similar to the Great Depression in the United States in the 1920’s. This scenario is located in the bottom right corner of the scenario space. The oil prices have gone through the roof, resulting in a negative impact on the macro economic growth. Technologic development has come to a stop, due to the macro economic crisis and an atmosphere of mistrust and hostility causes companies to focus on themselves. Thus the scenario is sketched by individualism, technologic halt and extremely expensive oil.

Research and development have come to a complete halt in most companies due to the economic recession. Centers for R&D have mostly closed their doors because the lack of funding from both the government and the industry. No real breakthrough innovations have emerged and the digital age have come to an abrupt stop after large scale internet fraud, espionage and invasion of privacy. Big-data analysis has not lived up to its promise, mainly due to the lack of hardware and software to cope with the large amounts of data. Although gasoline has become very expensive, the electric car has not been further developed. This resulted in the long distance transportation of people and freight to mainly occur by train. Online ordering has dropped, due to the feeling of invasion of privacy and people are more comfortable buying products at local markets.

Oil has become almost unaffordable due to the large scale economic recession and the halt in technological development. This has had a large impact on the transportation industry. Long distance freight transportation is done by either train (over land) or ship (overseas). If products are shipped by truck, this is done by fully packed mega-trucks to save fuel. Short distance freight transport is done only if absolutely necessary and only with full mega-trucks. This also resulted in longer delivery lead times, decreasing the e-commerce sales of stores.

In these dark times, people are very reserved and mistrust is predominant in the relationships within companies. Companies focus on themselves and try to be as independent of other companies as possible.

Of course this future scenario has an impact on the supply chain of Procter & Gamble. Some possible implications of the scenario on the supply chain of Dreft ADW are given below:

- On a plant level practically nothing has changed due to the lack of technological innovations. Only incremental changes in machinery are done and changeovers and quality checks are still done manually.
- Due to the technological halt, trucks are still the main mode of short distance transportation. However the high oil price forces transport to be done in bigger batches (by using larger trucks) and less frequent.
- Big-data analysis is too expensive, as the computers that can cope with such large amounts of information are considered 'super computers'. Therefore forecast is still a relatively large standard deviation. Furthermore, is has become increasingly difficult to access big-data as people become more concerned of their privacy.
- E-commerce has dropped, because lead times have become larger and internet use has decreased because of the concerns about privacy.
- Mistrust runs the industry, cooperation between manufacturer and retailer is very difficult, let alone cooperation between manufacturers. Communication is laborious and companies rather stay on their own than form a cooperation or joint ventures.
- This also means that there is no openness of information in the supply chain. Everyone accounts for their part and see the rest as not their business.

C.4 Scenario 3: "The Lean Era"

Although the first scenarios clearly indicate a good or bad economy, the third scenario sketches a more moderate image. Although not a real crisis has happened (Greece stayed in the Eurozone), the burden of the large financial dept has left its mark on Europe and the global economy. With respect to the three scenario space axes, this scenario is set in the corner of technological heydays, collectivism and extremely high oil prices.

As was expected, the oil price steadily rose to sky high rates over the next 15 years, due to all kinds of causes (overall small economic growth, turmoil in the Middle East, depleting oil reserves, taxes on oil etc.). This however triggered the industry to save costs and come up with technological solutions to the rising oil prices. The high oil rates have forced people to travel by train or buy an electric car. Even though this technology is now widely accepted and outperforms the current gasoline car, it is a luxury good. This is also the case for the freight industry where electric trucks are available, but expensive.

Technology is thriving in this scenario. People find new ways to cope with the high oil prices; high speed trains (from London to New York), electric cars, green energy, electric stoves etcetera. As stated before, electric cars are now the standard for people who can afford them, the rest will travel longer distances by public transport. A byproduct of these trends is the increased use of e-commerce. As people do not have the possibility to travel large distances, they would rather have their products delivered to them. This resulted in a 'lead-time war' where companies tried to outmarch each other on delivery lead time promises. An effect of this is the use of big-data by companies to serve the consumer in every need. Companies invest a therefore lot in R&D to make their company less dependent on oil (machinery changes, transport mode switches etc.) and big-data analysis has become highly important when it comes to accurate forecasting of sales and targeted marketing to customers.

There is a general feeling of trust in the industry. Companies see the importance of joint ventures and cooperation, creating an open and transparent working environment. FMCG companies have seen the importance of working together to increase margins and cut costs in a way that everybody wins. Vertical as well as horizontal cooperation is the norm and not sharing information is almost unthinkable.

The supply chain of Procter & Gamble would thus need to make some changes to deal with the impact this scenario has. Some possible implications of the scenario on the supply chain of Dreft ADW are given below:

- Within the manufacturing plant, the processes are almost fully automated and optimized, minimizing changeovers time, increasing capacity of the lines and increasing quality.
- Procter & Gamble would have to make a tradeoff between investing in electric trucks or stay with the conventional gasoline trucks. A hybrid option for gasoline mega trucks for the long distance freight transport over land and small(er) electric shuttle trucks for short distance.
- Big-data analysis is the leading method for forecasting. Accuracy of forecasting is very high reducing risks of going out of stock. Large piles of data are used to compute forecast and demand of customers at each time of the week. There is easy access to information as well as software and hardware to cope with these amounts of data.
- Because consumers have adapted to the internet completely and people do not travel by car anymore, e-commerce has risen as well as local buying. A war for customers is raging, reducing delivery lead times for online shopping in the FMCG industry.
- Decreasing delivery lead times, the need to reduce costs in order to increase margins and acknowledgement of core strengths of other companies are drivers for cooperation. Complete synchronized supply chains, where several companies act as one entity are the new normal. Furthermore far-reaching cooperation between rivaling companies such as Procter & Gamble and Unilever in the form of shared warehousing and transport have optimized supply chains.
- Within the supply chain the information and materials flow seamlessly through the network, creating an open and transparent atmosphere between the various actors.

Appendix D: Model Verification

The model was verified with several methods. The approach of Van Dam et al. (2012) was used in the verification process (van Dam et al., 2012). Several checks were executed and subsequently the model was closely examined and tested if the behavior of the model was correct. The following tests were performed:

- Recording and tracing agent behavior
- Minimal model testing: Sanity checks
- Full model sanity check

As expected, the first verification method that was used was the recording and tracing of the agent behavior.

D.1 Recording and tracing agent behavior

For each separate procedure it was tested whether the agents actually perform in the way that the modeler wants them to. This can be checked by providing the agents a fixed input of which the modeler knows the output. The different procedures have been tested separately and the findings are presented below. Not all functions have been described below, as some are so straightforward (calculating hourly sales from daily sales with constant sales during the day) that it was not necessary to mention them alone.

Setup Procedures

Creating Layout procedure

Input: Creation of the 5 agents in the interface, with information an supply links between them

Expected output: Graphical representation of the various agents and the links

Output: Graphical representation of the 5 agents and the information and supply links

Verified: yes

Initialize procedure

Input: Various values and lists for the global variables and player owned variables.

Expected output: The defined values as content for the variables. For example, safety stock of the Retailer X replenishment agent should be set to 500. Straightforward coding in Netlogo

Output: Although not checked for every separate variable (as it is straightforward defining of values), the ones that were checked gave the expected output.

Verified: yes.

Calculate timings procedure

Input: The inputs are the in the stakeholder analysis defined order-place and process timings for the 5 agents (respectively 10h, 11h, 12h, 13h, 14h for placing). This is more or less the same as for the initialize procedure.

Expected output: The order-place and process timings should be what we define them to be.

Output: When displaying the specific variable in simulation runs the timings are what they have been defined.

Go Procedures

Place order procedures

Agents: Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning and Production Planning

Input: The by stakeholder specified timings of order placings (respectively 10h, 11h, 12h, 13h, 14h) and fixed order amounts (30 units) and specified safety factors for the orders (1.2, 1, 1.2).

Expected Output: The expected output is that each agent respectively places the order with the specified order amount at the specified time, thereby creating a supply chain where each agent orders after the other.

Output: The output was as expected. The agents placed the orders at their upstream successor and the amounts were the right amounts.

Verified: yes.

Process order procedures

Agents: Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning and Production Planning

Input: The by stakeholder specified timings of order processing (respectively 6h, 10h, 11h, 12h, 13h) and fixed order amounts (30 units) and specified safety factors for the orders (1.2, 1, 1.2) that have been placed with the previous procedure.

Expected Output: The expected output is that each agent respectively processes the order with the specified order amount at the specified time, thereby creating a supply chain where each agent process the orders after the other. It is expected that inventory is directly updated after the order is processed with the order amount from the placed order.

Output: The output was as expected. The agents processed the orders given from their downstream predecessor and the amounts of product were correct. Also inventory levels are correctly updated in this step.

Verified: yes.

Receive order procedures

Agents: Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning and Production Planning

Input: The orders are processed and after the specified lead-times (X Hours) these orders arrive in the ordered amounts at the agent that has placed the order.

Expected Output: The expected output is that each agent respectively receives their order at the right time and in the right amount and correctly updates their inventory accordingly. The processed amount by the successor upstream in the supply chain is what is received by the agent.

Output: The output was as expected. The agents received the orders processed by the agent upstream in the right amount on the right time. The inventory is then updated subsequently with the right amount.

Verified: Yes.

Calculate regular sales procedures

Input: A fixed amount of weekly sales (30 units)

Expected Output: The expected output is the a random number around 1/7th of 30 units, generated by a random number function with a mean (1/7th of 30; the daily sales) and a standard deviation (25% of 1/7th of 30)

Output: After various runs (>100) the simulations showed that indeed random numbers were generated around 30 units.

Verified: Yes.

Calculate promotional sales procedures

This calculation depends on whether real-life data is used or not, if not, the procedure is exactly the same as for the calculation for the regular sales (and thus verified), if yes, the procedure verified below is used.

Input: A fixed amount of the weekly promotional sales (7000 units) of that week. This is taken from a list that is entered in the model.

Expected Output: The expected number is exactly 1/7th of the input.

Output: After various runs (>100) the simulations showed that indeed always 1/7th was shown

Verified: Yes.

Update promotion schedule, forecast-schedule and promotion realization procedures

These are three functions that perform the same operations but for three different lists with information.

Input: three lists that resemble a yearly schedule of promotions, forecasts and promotion realization over the tested fiscal year. These lists resemble the FY 14/15 of Procter & Gamble for a certain SKU. These lists need to be manually entered in Netlogo (copy/paste from an Microsoft Excel list).

Expected Output: After each week on the first day of the next week, the first number of the list should be removed at the front and put at the back of the list, as to make a circle. This way there is the possibility of running the same experiment for several years with the input of FY 14/15.

Output: The actual output is exactly as one would expect. At the designated time (first day of the week) the first number of the list is put at the back of the list.

Verified: Yes.

Calculating the amount of preload for a promotion procedure

Input: A fixed and known amount of forecasted promotional sales (taken from the forecast-schedule list) and the, from the stakeholder analysis taken percentages of preloads, for the different actors on the predefined times of the week are used as inputs for this procedure.

Expected Output: A rise in inventory (thus a preload) on the designated day of the week, with the designated amount of product.

Output: As expected. On the set times, the right amounts are preloaded.

Verified: Yes.

Calculating the order distribution during promotions procedure

Agents: Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning.

Input: A fixed amount of promotional sales, a distribution of orders (in percentages) of the various agents (retrieved from the stakeholder analysis) throughout the promotion week. For example, on Tuesdays, Retailer X pushes 25% of the total promotion forecast to the stores.

Expected Output: Replenishment of the various agent's DCs according to the distribution during the week.

Output: When the model is running one can clearly see that the replenishment of the various agent's DCs is according to the predefined schedule.

Verified: Yes.

Determining the uplift during a promotion procedure

Input: A fixed amount of promotional sales and a known initial promotional sales forecast. The amount of products sold with respect to the forecasted sales determines the uplift. For example if the forecast is 10 and sales are 15; the uplift is 1.5.

Expected Output: An uplift calculated as explained above.

Output: As expected.

Verified: Yes.

Determining returns of goods and their amounts procedure

Input: A fixed (too large) amount of products during a promotion at the DC of Retailer X, of which the remainder is returned if this is larger than 100 units. The amount of too much product is set to both more than 100 cases and less in separate runs.

Expected Output: Returns of the over shipped amount and no returns if less than 100 cases.

Output: As expected.

Verified: Yes.

Conclusion

As expected at the end of various runs all the errors were removed from the single procedures. The errors have been fixed and the procedures were tested until they passed the verification test. It can thus be said that the model computes the variables as intended.

D.2 Minimal model testing: Sanity checks

In this section it is verified whether or not the model behaves as it should as a whole when the model is fed very small settings. Do the agents place their orders in time, do they accept en process these and are the orders received in time, are promotion weeks incorporated and executed, etcetera. This test incorporates all the agents (Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning and Production Planning) and these agents behavior in terms of their execution of the different procedures. This section reports the findings on execution of the different procedures. In this test it was not checked whether the right numbers were used, but rather if the agent takes action on the times that he needs to. In chapter 7 it can be found what these procedures entail.

Place order procedures:

Agent: All agents except Raw Material Supply

Retailer X Replenishment: Place order – Executed as expected

Procter & Gamble Order Management: Place order – Executed as expected

Procter & Gamble Supply Planning: Place order – Executed as expected

Procter & Gamble Demand Planning: Place order – Executed as expected

Procter & Gamble Production Planning: Place order – Executed as expected

Process order procedures:

Agent: All agents

Retailer X Replenishment: Process order – Executed as expected

Procter & Gamble Order Management: Process order – Executed as expected

Procter & Gamble Supply Planning: Process order – Executed as expected

Procter & Gamble Demand Planning: Process order – Executed as expected

Procter & Gamble Production Planning: Process order – Executed as expected

Raw Material Supply: Process order – Executed as expected

Receive order procedures:

Agent: All agents except Raw Material Supply

Retailer X Replenishment: Receive order – Executed as expected

Procter & Gamble Order Management: Receive order – Executed as expected

Procter & Gamble Supply Planning: Receive order – Executed as expected

Procter & Gamble Demand Planning: Receive order – Executed as expected

Procter & Gamble Production Planning: Receive order – Executed as expected

New day procedures:

Agent: Retailer X Replenishment and Procter & Gamble Order Management

Retailer X Replenishment: Calculation of cumulative shelf availability – Executed as expected

Procter & Gamble Order Management: Calculation of SAMBC – Executed as expected

New week procedures

Agent: All agents

Retailer X Replenishment: Check for upcoming promotions – Executed as expected

Procter & Gamble Order Management: Check for upcoming promotions – Executed as expected

Procter & Gamble Supply Planning: Check for upcoming promotions – Executed as expected

Procter & Gamble Demand Planning: Check for upcoming promotions – Executed as expected

Procter & Gamble Production Planning: Check for upcoming promotions – Executed as expected

Upcoming promotion procedures

Sub-procedures: *Preloading and promotion week procedures*

Agent: *Retailer X Replenishment, Procter & Gamble Order Management, Supply Planning, Demand Planning*

Preload procedures

Retailer X Replenishment: Preloading orders – Executed as expected

Procter & Gamble Order Management: Preloading orders – Executed as expected

Procter & Gamble Supply Planning: Preloading orders – Executed as expected

Procter & Gamble Demand Planning: Process order – Executed as expected

Promotion week procedures

Retailer X Replenishment: Promo week order replenishment – Executed as expected

Procter & Gamble Order Management: Promo week order replenishment – Executed as expected

Procter & Gamble Supply Planning: Promo week order replenishment – Executed as expected

Procter & Gamble Demand Planning: Promo week order replenishment – Executed as expected

Conclusion

The test did not reveal any errors. The simple reason for this is that this test was actually performed after the model was finished. Many preliminary simulation runs were performed before a thorough verification test was done. The results of these tests have not been recorded. Be executing the test as reported, it is now double-checked that the model performs as it should and that the agents behave as intended.

D.3 Full model sanity check

As a final tests the model was executed with all internal logging functions, tracking the behavior of the different agents and the overall outcomes of the model. To pass this test, the model should behave as expected with no odd or impossible outcomes (negative inventory, no sales, negative service level etc.). Again this test was performed after the model was finished, so no real problems were expected here. In the process the model was tested several times and problems occurring during these tests were solved. After these various tests (which have not been logged), no further unexpected behavior was observed and therefore it can be said that the model operates as it is intended to. The test is considered to be passed and the model is therefore verified.

Appendix D: Netlogo code

In this appendix the Netlogo 5.2.0 code and an explanation of the code is given in the figure below.

```
globals [                                          ;; Globals are functions or information in the environment any agent can have acces to if he asks for it
  inventory-store                                  ;; all globals more or less speak for themselves, however at this point in time it is still an empty container (name) that can
  inventory-AHdc                                   ;; in the rest of the model these empty containers need to be defined.
  inventory-PGdc
  inventory-PGDem
  inventory-plant
  inventory-rawmat
  POSdata
  forecast-AH
  forecast-PG
  servicelevel
  shelf-availability
  missed-cases
  day
  week
  weekday
  hour
  promoschedule
  total-sales
  promotional-sales
  monday-sales
  total-missed-sales
  missed-sales
  uplift
  forecast-schedule
  forecast-realization
]

breed [players player]                             ;; multiple agents are players, a single agent is a player

directed-link-breed [supply-links supply-link]     ;; there are supply-links between players
supply-links-own [orders-filled pair-information-link]  ;; each link can have 2 data points stored, e.g. the orders-filled by agent upstream and
                                                   ;; the pair information link, that couples the order information of the player with supply

directed-link-breed [information-links information-link]  ;; there are also information-links between players
information-links-own [orders-placed back-orders]  ;; these have also 2 data points store, the orders placed and the backorders

players-own [                                      ;; as opposed to the globals, there is also information of which each agent has an own value
  inventory-position                               ;; and these can thus vary per agent. Same as for the globals, these are still just names and do not contain any information ye
  safety-stock
  promo-safety-stock
  preload
  role
  safety-factor
  last-received
  backlog
  process-time
  place-time
  MOQ
  demand-history
]

to setup                                           ;; with a to .... command, a function is called into action. If the setup button in the interface tab
  ca                                               ;; is pushed, the setup function is executed.
  set servicelevel 100
  layout                                           ;; layout is a function that is called into action when setup is executed and layout is described below
  initialize
  calc-timings
  reset-ticks
end

to go                                              ;; pushing the go button in the interface will run the model. If go is executed, it will perform the below
                                                   ;; functions for every tick until the model stops

  set day floor (ticks / 24)                       ;; each tick is one hour, a day is 24 ticks etc.
  set week floor (ticks / 168)
  set weekday (day - 7 * week + 1)
  set hour (ticks - 24 * day)

  ifelse first promoschedule = 1 [                 ;; this determines each tick if it is a promotional week, if is 1, then there is a promo, if 0, then not. promoschedule is defined below
    set POSdata daily-demand-promo]                ;; if there is a promo, POS data (the sales) is calculated by the function daily-demand-promo
  [set POSdata daily-demand]                       ;; if not so, POSdata is defined by the function daily-demand

  calc-monday-demand-promo                         ;; calls the function that calculates the monday demand promotions, to calculate the uplift
  determine-uplift                                 ;; determines, with the information from above, the uplift of a promotion
  calc-hourly-demand-promo                         ;; calls the function that calculates the promotional sales per hour

  place-order                                      ;; function that lets the agents place orders
  process-order                                    ;; function that lets the agents process orders
  receive-order                                    ;; function that lets the agents receive orders
  summarize                                        ;; function that summarizes and updates information

  calc-servicelevel                                ;; function that calculates the service level
  recalc-promoschedule                             ;; updates the promotional schedule placed below
  if real-life-data = 1[                           ;; when run with real-life-date (switch in the interface), the forecast of promotions is updated according to historical data
  update-forecast]
  preload-promotion                                ;; calls the funtion into action that calculates and executes preloading of the DC's
  reset-promo-safety-stock                         ;; function that calculates the safety stock levels for a promotion week

  update-safety-stock                              ;; updates the actual safety-stock settings of the agents

  if returns = true[                               ;; if the returns are true (button in interface), the function return-orders is run
  return-orders]

  if interconnectivity = 2 [                       ;; if interconnectivity is 2 (in interface), timings are updated for a monday afternoon release
  update-timings]

  if week = new-sales-week[                        ;; This function is build in, because in real-life due to external factors a sudden increase in the otherwise relatively stable sales can happen.
    set regular-sales new-sales                    ;; if the week nr. (defined above) is the new-sales-week (defined in the interface), the regular sales are set to new-sales (defined in interface)
    set safety-stock-AHdc new-safety-stock]        ;; and safety-stock at the AH DC is set to the value of the new-safety-stock (defined in interface)

  tick                                             ;; a tick is recorded
  if day = 365 * years-of-simulation [stop]        ;; if the years of simulation (defined in interface) is reached, the go-procedure stops
  ifelse (inventory-AHdc - safety-stock-AHdc) > 100  ;; this is a piece of code that states whether or not returns are made between AH DC and PG DC. If there is more than 1 pallet left at the AH DC after
  [set returns true]                               ;; a promotion returns are made, otherwise not.
  [set returns false]

end


;;------------------------------;;
;; Perfrom the Setup Operations ;;
;;------------------------------;;
```

```
to layout                                                   ;; the layout operation "make" the agents and physically generate the agents that make the decisions in this supply chain
  set-default-shape players "circle"
  set-default-shape information-links "arc"
  set-default-shape supply-links "arcmulti"

  create-players 1 [                                        ;; The first player to be generated is the agent Albert Heijn, who are responsible for store replenishment and manage store inventory. The other
    setxy -25 0                                             ;; players are defined in the same way and together make up for the model.
    set color [0 160 226]
    set role "Albert Heijn"
    set size 5
    set label word "AH-" "1"
  ]

  create-players 1 [
    setxy -15 0
    set color [0 61 175]
    set role "PGOM"
    set size 5
    set label word "PG-" "1"
  ]

  create-players 1 [
    setxy -5 0
    set color [0 61 175]
    set role "PGSup"
    set size 5
    set label word "PG-" "2"
  ]

  create-players 1 [
    setxy 5 0
    set color [0 61 175]
    set role "PGDem"
    set size 5
    set shape "square"
    set label word "PG-" "3"
  ]


  create-players 1 [
    setxy 15 0
    set color [0 61 175]
    set role "PGProd"
    set size 5
    set label word "PG-" "4"
    set shape "square"
  ]

  create-players 1 [
    setxy 25 0
    set color [157 157 157]
    set role "RawMat"
    set size 5
    set label word "RM-" "1"
    set shape "house"
  ]
                                                            ;; In this piece of code the links between agents are defined. If these are not defined, agents cannot interact.
  ask players with [role = "Albert Heijn"] [
    create-information-links-to players with [role = "PGOM"]       ;; create information and supply links between Albert Heijn and PG Operations Management
    create-supply-links-from players with [role = "PGOM"]
  ]

  ask players with [role = "PGOM"] [
    create-information-links-to players with [role = "PGSup"]      ;; create information and supply links between PG Operations Management and PG Supply Planning
    create-supply-links-from players with [role = "PGSup"]
  ]

  ask players with [role = "PGSup"] [
    create-information-links-to players with [role = "PGDem"]      ;; create information and supply links between PG Supply Planning and PG Demand Planning
    create-supply-links-from players with [role = "PGDem"]
  ]

  ask players with [role = "PGDem"] [                              ;; A side note to the P&G Demand planning Agent. This has a virtual stock, that the agent manages. This is done for easier programming.
    create-information-links-to players with [role = "PGProd"]
    create-supply-links-from players with [role = "PGProd"]        ;; create information and supply links between PG Demand Planning and PG Production Planning
  ]

  ask players with [role = "PGProd"] [
    create-information-links-to players with [role = "RawMat"]
    create-supply-links-from players with [role = "RawMat"]        ;; create information and supply links between PG Production Planning and Raw Material Supplier
  ]

  ask supply-links [                                               ;; define the pair information link of each supply link, the link with the same ends
    set pair-information-link information-links with [end1 = [end2] of myself and end2 = [end1] of myself]
  ]
end



to initialize                                                      ;; to initialize is to give globals and information of the players values, before the simulation starts.
  set day 0                                                        ;; thus set the value of the day at the number zero.

  ;; Promoschedule is list of zeros and ones, that resembles the promotions schedule of a Dreft ADW SKU throughout the year. If there is a one, there is a promotion, if there is a zero, there is no promotion.
  ;; THIS LIST NEEDS TO BE LOADED MANUALLY FOR EACH NEW SKU THAT IS TESTED FROM THE EXCEL FILE NETLOGO INPUT.
  set promoschedule (list 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 )

  ;; The forecast-schedule is a list that has the historical (real-life) values of the initial forecasts (X - 4) of a certain SKU. For both preloading and promo production, these values are used.
  ;; it must be noted that the whole period after a promotion until the next promotion has the value of this next promotion, this way the model loads the right initial forecast.
  ;; THIS LIST NEEDS TO BE LOADED MANUALLY FOR EACH NEW SKU THAT IS TESTED FROM THE EXCEL FILE NETLOGO INPUT.
  set forecast-schedule (list 375  375  375  375  500  500  500  500  500  500  102  102  102  102  109  109  109  109  1  1  1  7500  7500  7500  7500  7500  7500  7500  7500  2000  2000  2000  2000  4000  4000
)

  ;; The forecast-realization is a list that has the historical (real-life) values of the actual promotional week sales. It works in the same way as the forecast-schedule.
  ;; THIS LIST NEEDS TO BE LOADED MANUALLY FOR EACH NEW SKU THAT IS TESTED FROM THE EXCEL FILE NETLOGO INPUT.
  set forecast-realization (list 278  278  278  278  412  412  412  412  412  412  155  155  155  155  958  958  958  958  1134  1134  1134  8154  8154  8154  8154  8154  8154  8154  8154  1187  1187  1187  1187
)



  set missed-cases 0                                               ;; in this section some globals are given a value
  set promotional-sales 0
  set total-sales 1
  set total-missed-sales 0
  set uplift 1


  ask players [                                                    ;; in this section some player owned information is given values, the first part is for all players.
    set backlog 0                                                  ;; thus the backlog of each player is set to zero at the beginning of the simulation
    ifelse visibility = true [                                     ;; this part of the code gives safety-factors with variable visibility
      set safety-factor 1
      set forecast-PG 1
      set forecast-AH 1.2]
    [set safety-factor 1                                           ;; thus if there is no visibility (no sharing of POS data) there are two safety-factors
      set forecast-PG 1.2
      set forecast-AH 1.2]
    set POSdata 0
    set promo-safety-stock 0

    if role = "Albert Heijn" [                                     ;; this section gives the various player owned information values. Only important or remarkable lines will be discussed
      set initial-store-inv safety-stock-store
      set inventory-store initial-store-inv
      set inventory-position inventory-store - backlog
      set safety-stock safety-stock-store                          ;; safety stock of Albert Heijn has gotten the value given to safety-stock-store.
      set forecast-AH forecast-AH
      set MOQ MOQ-store
      ask my-out-information-links[                                ;; this gives the information that the outgoing information link (thus information flowing from AH to PGOM) has a value.
        set orders-placed 0                                        ;; thus at the start of the experiment, the amount of order placed at PGOM is zero.
        set back-orders 0                                          ;; and at the same time also no back orders.
      ]

      ask my-in-supply-links [                                     ;; same as for the information-links above, this defines the information that the supply link holds.
        set orders-filled n-values lead-time-AHdc-store [0]        ;; the supply-link is a list of zeros that resemble the delivery lead time. With each tick (hour in the model) an order that is placed at the end of
      ]                                                            ;; the list moves one place towards the beginning. Once at the beginning, the order virtually arrives at the orderer.

      set demand-history n-values record-length [""]               ;; creates a list that can log the demand history (thus store sales) in a list with the length of record-length (defined in the interface)
       ]


    if role = "PGOM" [                                             ;; almost the same executions as for the agent Albert Heijn, but then with the information that is applicable to the PGOM agent.
      set initial-store-inv safety-stock-AHdc
      set inventory-AHdc initial-AHdc-inv
      set inventory-position inventory-AHdc - backlog
      set safety-stock safety-stock-AHdc
      set MOQ MOQ-AHdc
      ask my-out-information-links[
        set orders-placed 0
        set back-orders 0
      ]

      ask my-in-supply-links [
        set orders-filled n-values lead-time-PGdc-AHdc [0]
      ]
```

```
    set demand-history n-values record-length [""]                 ;; this is actually a piece of code that is not used in the current model version. It might be used to find optimal safety-stock levels,
    ]                                                              ;; but therefore one would need to make a piece of code that calculates the desired safety-stock level according to the demand history.

  if role = "PGSup" [                                              ;; and again the same for PGSupply
    set initial-store-inv safety-stock-PGdc
    set inventory-PGdc initial-PGdc-inv
    set inventory-position inventory-PGdc - backlog
    set safety-stock safety-stock-PGdc
    set MOQ MOQ-PGdc
    ask my-out-information-links[
      set orders-placed 0
      set back-orders 0
    ]

    ask my-in-supply-links [
      set orders-filled n-values 35 [0]
    ]

    set demand-history n-values record-length [""]
    ]

  if role = "PGDem" [
    set inventory-PGDem 80000
    set inventory-position inventory-PGDem - backlog
    set safety-stock 80000
    set MOQ MOQ-PGdc
    set forecast-PG forecast-PG
    ask my-out-information-links[
      set orders-placed 0
      set back-orders 0
    ]

    ask my-in-supply-links [
      set orders-filled n-values 1 [0]
    ] ]

  if role = "PGProd" [
    set inventory-plant 50000                                      ;; The inventory at the plant is kept constant. It was ultimately chosen to be constant, as the production of Dreft ADW alone for AH will probably
    set safety-stock 50000                                         ;; not cause the inventory of raw materials at the plant to run out.
    set inventory-position inventory-plant - backlog
    ask my-out-information-links[
      set orders-placed 0
      set back-orders 0
    ]

    ask my-in-supply-links [
      set orders-filled n-values 1 [0]
    ]
    set demand-history n-values record-length [""]
    ]

  if role = "RawMat" [                                             ;; The inventory at the raw-material supplier is also kept constant
    set inventory-rawmat 1000000
   ]
  ]
end

to calc-timings                                                     ;; The calculate timings function is to determine at what time in the day orders are placed and/or processed.
if interconnectivity = 1 or interconnectivity = 2[                  ;; These are the general timing that are used when the processes are not aligned (interconnectivity 1) or monday afternoon release (interc. 2)
  ask players with [role = "Albert Heijn"][
    set process-time 6
    set place-time 9 ]

  ask players with [role = "PGOM"][
    set process-time 10
    set place-time 11]

  ask players with [role = "PGSup"][
    set process-time 11
    set place-time 12]

  ask players with [role = "PGDem"][
    set process-time 12
    set place-time 13]

  ask players with [role = "PGProd"][
    set process-time 13
    set place-time 14] ]

if interconnectivity = 3[                                           ;; The order place and process timings when processes are aligned (interconnectivity 3)
  ask players with [role = "Albert Heijn"][
    set process-time 18
    set place-time 19 ]

  ask players with [role = "PGOM"][
    set process-time 20
    set place-time 21]

  ask players with [role = "PGSup"][
    set process-time 21
    set place-time 22]

  ask players with [role = "PGDem"][
    set process-time 23
    set place-time 23]

  ask players with [role = "PGProd"][
    set process-time 13
    set place-time 13] ]
end

;;--------------------------;;
;; Perfrom the Go Operations ;;
;;--------------------------;;


to place-order                                                      ;; The pieces of code below resemble the operations that are taken by the agents when they place an order to an agent upstream.

  ask players with [role = "Albert Heijn"] [                                                     ;; The actions that are taken are straight forward and I will only explain one
   ifelse hour = place-time [                                                                    ;; This calls up an ifelse, thus
      let order-amount max list (ceiling(((safety-stock - inventory-position) * forecast-AH) / MOQ) * MOQ) 0 ;; if its time to order, the order amount is calculated and
      ask my-out-information-links [set orders-placed order-amount] ] [                          ;; this is put in the information link to the agent upstream as an orders-placed.
      let order-amount  0                                                                        ;; if it is not the time to place an order this order amount is set to zero.
      ask my-out-information-links [set orders-placed order-amount] ] ]

  ask players with [role = "PGOM"] [
      ifelse hour = place-time [
      let order-amount max list (ceiling(((safety-stock - inventory-position) * safety-factor) / MOQ) * MOQ) 0
      ask my-out-information-links [set orders-placed order-amount] ] [
      let order-amount 0
      ask my-out-information-links [set orders-placed order-amount] ] ]

  ask players with [role = "PGSup"] [
    ifelse hour = place-time [
      ifelse (inventory-position - safety-stock) < 0 [
      let order-amount max list (ceiling(((safety-stock - inventory-position) * forecast-PG) / MOQ) * MOQ) 0
      ask my-out-information-links [set orders-placed order-amount] ]
      [let order-amount 0
      ask my-out-information-links [set orders-placed order-amount] ] ][
      let order-amount max list (ceiling(((safety-stock - inventory-position) * forecast-PG) / MOQ) * MOQ) 0
      ask my-out-information-links [set orders-placed order-amount] ] ]

  ask players with [role = "PGDem"] [
    ifelse hour = place-time [
      ifelse (inventory-position - safety-stock) < 0 [
      let order-amount max list ((safety-stock - inventory-position) * safety-factor)  0
      ask my-out-information-links [set orders-placed order-amount] ]
      [let order-amount 0
      ask my-out-information-links [set orders-placed order-amount] ] ][
      let order-amount max list ((safety-stock - inventory-position) * safety-factor)  0
      ask my-out-information-links [set orders-placed order-amount] ] ]

  ask players with [role = "PGProd"] [
    if hour = place-time [
      let order-amount max list ((safety-stock - inventory-position) * safety-factor) 0
      ask my-out-information-links [set orders-placed order-amount] ] ]
end



to receive-order                                                    ;; these are the receive order operations again explained for only one agent, as the rest behaves under the same rules

  ask players with [role = "Albert Heijn"][                         ;;
      set last-received sum [first orders-filled] of my-in-supply-links  ;; the last-received are the orders that have arrived at the AH stores at this tick, thus often zero, unless a truck arives, then orders-filled
      ask my-in-supply-links [set orders-filled but-first orders-filled] ;; here the list that resembles the delivery lead-time of the agent is updated and, by removing the first number of the list
      set inventory-store inventory-store + last-received]          ;; the inventory of the store is subsequently updated with the value that is last-received plus what is still in store.

  ask players with [role = "PGOM"][
      set last-received sum [first orders-filled] of my-in-supply-links
      ask my-in-supply-links [set orders-filled but-first orders-filled]
      set inventory-AHdc inventory-AHdc + last-received]
```

```
 ask players with [role = "PGSup"][
     set last-received sum [first orders-filled] of my-in-supply-links
     ask my-in-supply-links [set orders-filled but-first orders-filled]
     set inventory-PGdc inventory-PGdc + last-received]

 ask players with [role = "PGDem"][
     set last-received sum [first orders-filled] of my-in-supply-links
     ask my-in-supply-links [set orders-filled but-first orders-filled]
     set inventory-PGDem inventory-PGDem + last-received]

 ask players with [role = "PGProd"][
     set last-received sum [first orders-filled] of my-in-supply-links
     ask my-in-supply-links [set orders-filled but-first orders-filled]
     set inventory-plant inventory-plant + last-received]

 ask players with [role = "RawMat"]
 [set inventory-rawmat 1000000]                            ;; inventory at the raw material supplier is constant

end

to process-order                                        ;; these are the operations that are done to process an order of a downstream agent

 ask players with [role = "Albert Heijn"][

     let new-orders 0                                   ;; new-orders is a new information bucket that is defined for this piece of code (e.g. not a global)
     ifelse hour = process-time [                       ;; when the time is right for processing the order
     set new-orders POSdata][                           ;; the new-orders becomes the POS-data value (thus new-orders becomes that day's sales)
     set new-orders 0]                                  ;; otherwise there are no sales processed and new-orders (the trigger for the rest of the processing operations) remains zero.

     if first promoschedule != 1 and weekday < 6[       ;; some conditions to when the below operations will be performed
     set demand-history lput new-orders demand-history  ;; actually a piece of code that can be used to update the demand history to update safety-stocks, but not used in this model version
     set demand-history but-first demand-history]

     let orders-requested new-orders                    ;; orders-requested, a new shell of information that is used later on in this process gets the value of the new-orders
     let orders-to-ship min list orders-requested inventory-store  ;; the orders that will be shipped are the minimum of the orders-requested, or the inventory-store. This is to have not a negative store-inventory value

     ifelse hour = process-time[
     set missed-sales max list 0 (missed-sales - inventory-store + new-orders)][  ;; the missed-sales are recorded here
     set missed-sales 0]

     set backlog 0                                      ;; normally the orders that cannot be filled due to out of stocks are recorded here, but the store does not give backorders to end consumers, thus zero.

     let rest-amount orders-to-ship                     ;; defining the information bucket rest-amount

     foreach sort my-out-supply-links [
       ask ? [                                                 ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair information link
         let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
         let ship-to-this-link 0                               ;; if no order, ship nothing, and put 0 in the supply link
         if orders-requested > 0 [                             ;; if positive order, ship according to the quota
           set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
         ]                                                     ;; note that we use ceiling to guarantee the integrity of the shipping quantity
         set rest-amount rest-amount - ship-to-this-link
         set orders-filled lput ship-to-this-link orders-filled      ;; put the ship quantity at the last place of the supply pipeline
         ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair information link
       ]
     ]

      set inventory-store inventory-store - orders-to-ship          ;; inventory-store is updated

      set total-sales total-sales + orders-to-ship                  ;; total-sales are updated

      set total-missed-sales total-missed-sales + missed-sales ]    ;; total-missed-sales are updated


 ask players  with [role = "PGOM"][                        ;; FOR THIS AGENT THE SAME PROCEDURES ARE OCCURING AS FOR THE ALBERT HEIJN AGENT

      let new-orders 0
      ifelse hour = process-time [
      set new-orders sum [orders-placed] of my-in-information-links ][
      set new-orders 0]

      if first promoschedule = 0 and new-orders < 100 and new-orders > 0[
      set demand-history lput new-orders demand-history
      set demand-history but-first demand-history]


      let orders-requested new-orders + backlog
      let orders-to-ship min list orders-requested inventory-AHdc


      ifelse hour = process-time[
      set backlog max list 0 (backlog - inventory-AHdc + new-orders)][
      set backlog 0]

      let rest-amount orders-to-ship

      foreach sort my-out-supply-links [
        ask ? [                                                ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair demand link
          let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
          let ship-to-this-link 0                              ;; if no order, ship nothing, and put 0 in the supply link
          if orders-requested > 0 [                            ;; if positive order, ship according to the quota
            set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
          ]                                                    ;; note that we use ceiling to guarantee the integrity of the shipping quantity
          set rest-amount rest-amount - ship-to-this-link
          set orders-filled lput ship-to-this-link orders-filled     ;; put the ship quantity at the last place of the supply pipeline
          ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair demand link
        ]
      ]

      set inventory-AHdc inventory-AHdc - orders-to-ship

      set missed-cases missed-cases + backlog]

 ask players with [role = "PGSup"][                        ;; FOR THIS AGENT THE SAME PROCEDURES ARE OCCURING AS FOR THE ALBERT HEIJN AGENT
      let new-orders 0
      ifelse hour = process-time [
      set new-orders sum [orders-placed] of my-in-information-links][
      set new-orders 0]
```

```
    if first promoschedule = 0 and new-orders < 1000 and new-orders > 0[
    set demand-history lput new-orders demand-history
    set demand-history but-first demand-history]

    let orders-requested new-orders + backlog
    let orders-to-ship min list orders-requested inventory-PGdc

    set backlog max list 0 (backlog - inventory-PGdc + new-orders)

    let rest-amount orders-to-ship

    foreach sort my-out-supply-links [
      ask ? [                                                ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair demand link
        let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
        let ship-to-this-link 0                              ;; if no order, ship nothing, and put 0 in the supply link
        if orders-requested > 0 [                            ;; if positive order, ship according to the quota
          set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
        ]                                                    ;; note that we use ceiling to guarantee the integrity of the shipping quantity
        set rest-amount rest-amount - ship-to-this-link
        set orders-filled lput ship-to-this-link orders-filled              ;; put the ship quantity at the last place of the supply pipeline
        ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair demand link
      ]
    ]

    set inventory-PGdc inventory-PGdc - orders-to-ship
  ]


ask players with [role = "PGDem"][                           ;; FOR THIS AGENT THE SAME PROCEDURES ARE OCCURING AS FOR THE ALBERT HEIJN AGENT
    let new-orders 0
    ifelse hour = process-time [
    set new-orders (sum [orders-placed] of my-in-information-links) * forecast-PG]
    [set new-orders 0]

    let orders-requested new-orders + backlog
    let orders-to-ship min list orders-requested inventory-PGDem


    set backlog max list 0 (backlog - inventory-plant + new-orders)

    let rest-amount orders-to-ship

    foreach sort my-out-supply-links [
      ask ? [                                                ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair demand link
        let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
        let ship-to-this-link 0                              ;; if no order, ship nothing, and put 0 in the supply link
        if orders-requested > 0 [                            ;; if positive order, ship according to the quota
          set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
        ]                                                    ;; note that we use ceiling to guarantee the integrity of the shipping quantity
        set rest-amount rest-amount - ship-to-this-link
        set orders-filled lput ship-to-this-link orders-filled ;; put the ship quantity at the last place of the supply pipeline
        ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair demand link
      ]
    ]

    set inventory-PGDem inventory-PGDem - orders-to-ship
  ]

ask players with [role = "PGProd"][                          ;; FOR THIS AGENT THE SAME PROCEDURES ARE OCCURING AS FOR THE ALBERT HEIJN AGENT

    let new-orders 0
    ifelse hour = process-time [
    set new-orders sum [orders-placed] of my-in-information-links][
    set new-orders 0]

    if first promoschedule = 0 and new-orders < 1000 and new-orders > 0[
    set demand-history lput new-orders demand-history
    set demand-history but-first demand-history]

    let orders-requested new-orders + backlog
    let orders-to-ship min list orders-requested inventory-plant

    set backlog max list 0 (backlog - inventory-plant + new-orders)

    let rest-amount orders-to-ship

    foreach sort my-out-supply-links [
      ask ? [                                                ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair demand link
        let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
        let ship-to-this-link 0                              ;; if no order, ship nothing, and put 0 in the supply link
        if orders-requested > 0 [                            ;; if positive order, ship according to the quota
          set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
        ]                                                    ;; note that we use ceiling to guarantee the integrity of the shipping quantity
        set rest-amount rest-amount - ship-to-this-link
        set orders-filled lput ship-to-this-link orders-filled              ;; put the ship quantity at the last place of the supply pipeline
        ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair demand link
      ]
    ]

    set inventory-plant inventory-plant - orders-to-ship
  ]

ask players with [role = "RawMat"][                          ;; FOR THIS AGENT THE SAME PROCEDURES ARE OCCURING AS FOR THE ALBERT HEIJN AGENT

    let new-orders 0
    ifelse hour = 16 [
    set new-orders sum [orders-placed] of my-in-information-links][
    set new-orders 0]


    let orders-requested new-orders + backlog
    let orders-to-ship min list orders-requested inventory-plant

    set backlog max list 0 (backlog - inventory-rawmat + new-orders)

    let rest-amount orders-to-ship

    foreach sort my-out-supply-links [
      ask ? [                                                ;; quota to each supply link is proportional the sum of back-orders and new orders of the pair demand link
        let quota sum [back-orders] of pair-information-link + sum [orders-placed] of pair-information-link
        let ship-to-this-link 0                              ;; if no order, ship nothing, and put 0 in the supply link
        if orders-requested > 0 [                            ;; if positive order, ship according to the quota
          set ship-to-this-link min list ceiling (quota * orders-to-ship / orders-requested) rest-amount
        ]                                                    ;; note that we use ceiling to guarantee the integrity of the shipping quantity
```

```
        set rest-amount rest-amount - ship-to-this-link
        set orders-filled lput ship-to-this-link orders-filled                 ;; put the ship quantity at the last place of the supply pipeline
        ask pair-information-link [set back-orders max list 0 (quota - ship-to-this-link)]  ;; update the back-orders in the pair demand link
      ]
    ]

    set inventory-rawmat inventory-rawmat - orders-to-ship
  ]
end

to summarize
  ask players with [role = "Albert Heijn"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-store + pipeline - backlog           ;; recalculate the inventory position
  ]

  ask players with [role = "PGOM"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-AHdc + pipeline - backlog            ;; recalculate the inventory position
  ]

  ask players with [role = "PGSup"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-PGdc + pipeline - backlog            ;; recalculate the inventory position
  ]

  ask players with [role = "PGDem"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-PGDem + pipeline - backlog           ;; recalculate the inventory position
  ]

  ask players with [role = "PGProd"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-plant + pipeline - backlog           ;; recalculate the inventory position
  ]

  ask players with [role = "RawMat"][
    let pipeline sum [sum orders-filled] of my-in-supply-links            ;; calculate the pipeline inventory (inventory in-transit) for each player
    set inventory-position inventory-plant + pipeline - backlog           ;; recalculate the inventory position
  ]

end


;;-----------------------------------;;
;; Update the various side operations ;;
;;-----------------------------------;;

to-report daily-demand                                                    ;; This is to calculate the daily demand of the consumer
  let demand 0
  set regular-sales regular-sales

  if interconnectivity = 1
  [ifelse hour = 6
    [set demand floor (random-normal regular-sales (regular-sales / 4))   ;; demand is randomly generated from the regular-sales with a sigma of 25%
      if demand < 0[
        set demand 0]]
    [report 0]
  report demand]

  if interconnectivity = 2                                                ;; same operations but then for increased interconnectivity (important when this information is shared)
  [ifelse hour = 6
    [set demand floor (random-normal regular-sales (regular-sales / 4))
      if demand < 0[
        set demand 0]]
    [report 0]
  report demand]

  if interconnectivity = 3                                                ;; same operations for interconnectivity 3
  [ifelse hour = 18
    [set demand floor (random-normal regular-sales (regular-sales / 4))
      if demand < 0[
        set demand 0]]
    [report 0]
  report demand]

end

to calc-servicelevel                                                      ;; function to calculate the service-level over the simulation run-time.
  if hour = 0 [
    set servicelevel ((1 -(missed-cases / total-sales)) * 100)]
  if hour = 0 [
    set shelf-availability ((1 - (total-missed-sales / total-sales)) * 100)]  ;; calculates the shelf-availability
end



;;-------------------------------------;;
;; Update operations for promotion week ;;
;;-------------------------------------;;

to update-forecast
  if weekday = 1 and hour = 0[                                                   ;; this function updates the forecast schedule, the list with whether or not there is a promotion. At the beginning of each week,
    set promo-forecast first forecast-schedule                                   ;; the promo-forecast (the expected forecast for the nearest upcoming promotion) is set to the value that is at the beginning of the
    set forecast-schedule lput first forecast-schedule forecast-schedule         ;; forecast schedule. This forecast schedule is also updated, by putting the first in line at the end, moving all values one place.
    set forecast-schedule but-first forecast-schedule
  ]

  if weekday = 1 and hour = 0[                                                   ;; at the beginning of each week, the same happens for the forecast-realization list, the first value is put at the end.
    set forecast-realization lput first forecast-realization forecast-realization
    set forecast-realization but-first forecast-realization
  ]
end

to recalc-promoschedule                                                   ;; same as for the above, updating the list
  if weekday = 1 and hour = 0[
    set promoschedule lput first promoschedule promoschedule
    set promoschedule but-first promoschedule
  ]
end

to-report daily-demand-promo                                              ;; this function reports the daily demand during a promotion for the different interconnectivity levels. The promotional sales are calculated in a later function.
    if interconnectivity = 1[
      ifelse weekday > 1 and hour = 6
      [report promotional-sales][
        report 0]]

    if interconnectivity = 2[
      if weekday < 3 and hour = 18
      [report promotional-sales]
      ifelse weekday > 2 and hour = 6
      [report promotional-sales][
        report 0]]

    if interconnectivity = 3[
      ifelse weekday >= 1 and hour = 18
      [report promotional-sales][
        report 0]]

end

to preload-promotion                                                      ;; the preload-promotion function generates via several calculations the amount of preload that will be pushed to the various DC's and stores
  let forecast-stock 0                                                    ;; forecast-stock is information that is newly generated each tick at this step
  let preproduction 0                                                     ;; preproduction is information that is newly generated each tick at this step
  set forecast-stock butfirst promoschedule                               ;; forecast-stock is defined here as the list promoschedule, without the first number; it looks at the promoschedule and sees if there is a promotion the next week
  set preproduction butfirst forecast-stock                               ;; same as the forecast-stock, but looks two weeks ahead instead of one.


  ifelse first forecast-stock = 1 and weekday >= 5                                                                          ;; this line defines when the preloading of the stores should happen i.e. friday before promotion
  [if weekday = 6 and hour >= 0 [ask players with [role = "Albert Heijn"][set preload (promo-forecast * 0.25 + safety-stock-store)]] ;; sets the preload to 25% on the saturday before a promotional forecast
   if weekday = 7 and hour >= 0 [ask players with [role = "Albert Heijn"][set preload (promo-forecast * 0.6 + safety-stock-store)]]] ;; sets preload to 60% of the promotional forecast
  [ask players with [role = "Albert Heijn"][set preload 0] ]                                                                ;; when it is not a time for preloading, this is set to zero

  ifelse first forecast-stock = 1 and weekday = 4                                        ;; this regulates the pre-loading of the Albert Heijn DC the weekend for a promotion
  [ask players with [role = "PGOM"][set preload (promo-forecast * 0.65 + safety-stock-AHdc)] ]  ;; 65% of the total promotional forecast is then shipped to the DC of AH
  [ask players with [role = "PGOM"][set preload 0] ]                                     ;; otherwise zero..

  if first forecast-stock = 1 and weekday = 7 and interconnectivity <= 3                    ;; this piece of code determines the safety-stock during a promotional week when processes are not completely aligned (connectivity 1 & 2)
  [ask players with [role = "PGOM"][set promo-safety-stock promo-forecast / 7 + safety-stock-AHdc]] ;; the promotional safety stock is the regular safety stock of the AH DC plus the expected daily sales during the specific promotion

  ifelse first preproduction = 1 and weekday = 6                                            ;; these lines in the code determine the replenishment of the PG DC before a promotion, thus the preproduction.
  [ask players with [role = "PGSup"][set preload (promo-forecast * 0.35 + safety-stock-PGdc)] ]   ;; the preproduction is 35% 2 weeks before the promotion
  [ifelse first forecast-stock = 1 and weekday = 2 and transparency = 1                     ;; then it depends on whether or not there is transparency (1 = no, 2 = yes) if more volume is pushed to the P&G DC
    [ask players with [role = "PGSup"][set preload (promo-forecast * 0.7 + safety-stock-PGdc)] ]  ;; if transparency = 1, 70% of the total volume is pushed to this DC
    [ask players with [role = "PGSup"][set preload 0] ] ]                                   ;; if not so, this volume is not pushed to the DC, triggering production in a later stage

  ifelse first preproduction = 1 and weekday = 6                                            ;; this piece of code is the same as above for the PGSUP, but now it regulates the 'virtual DC' of the agent PGDEM.
  [ask players with [role = "PGDem"][set preload (promo-forecast * 0.35 + 80000)] ]
  [ifelse first forecast-stock = 1 and weekday = 2 and transparency = 1
    [ask players with [role = "PGDem"][set preload (promo-forecast * 0.7 + 80000)] ]
    [ask players with [role = "PGDem"][set preload 0] ] ]
```

```
end

to reset-promo-safety-stock                                   ;; this function 'resets' the safety stock of the various agents during a promotion week, to have a gradual replenishment throughout the week
 if interconnectivity = 1 or interconnectivity = 2[
   if first promoschedule = 1 and weekday = 1                 ;; on the monday there is volume pushed to the stores of 1 day expected promotional sales
     [ask players with [role = "Albert Heijn"][set promo-safety-stock promo-forecast / 7 + safety-stock-store]]
   if first promoschedule = 1 and weekday = 2                 ;; on day two, Albert Heijn (over) reacts to an uolift and 25% of the remaining expected sales is pushed to the stores
     [ask players with [role = "Albert Heijn"][set promo-safety-stock  (((promo-forecast * uplift) * 0.25) - promo-forecast / 7  + inventory-store)]]
   if first promoschedule = 1 and weekday > 2 and weekday <= 7[          ;; the rest of the week, the remainder of the expected sales that is (intitial forcast * (1 - 60%) * (1 - 25%)
    ifelse inventory-store >= safety-stock-store                         ;; is pused to the stores of Albert Heijn.
     [ask players with [role = "Albert Heijn"][set promo-safety-stock inventory-store + (promo-forecast * uplift) / 7 * 0.4 * 0.75  ] ]
     [ask players with [role = "Albert Heijn"][set promo-safety-stock safety-stock-store + (promo-forecast * uplift) / 7 * 0.4 * 0.75  ] ]]
   if first promoschedule = 1 and weekday = 7                            ;; On the last day of the promotion (sunday), the safety-stock of the stores is set to non-promo week.
     [ask players with [role = "Albert Heijn"][set promo-safety-stock safety-stock-store] ]


   if first promoschedule = 1 and weekday = 1                                  ;; the promotional week actions are also taken for the PGOM agent.
    [ask players with [role = "PGOM"][set promo-safety-stock promo-forecast / 7 + safety-stock-AHdc] ]    ;; these are a bit simpler, as apart from the pre-load, the replenishment is evenly distributed over the whole week.
   if first promoschedule = 1 and weekday >= 2 and weekday < 7
     [ask players with [role = "PGOM"][set promo-safety-stock (((promo-forecast * uplift) / 7 ) + safety-stock-AHdc)] ]    ;; only from tuesday on the uplift is factored in into the safety-stock.
   if first promoschedule = 1 and weekday = 7
    [ask players with [role = "PGOM"][set promo-safety-stock safety-stock-AHdc] ]
   if last promoschedule = 1 and weekday = 1
    [ask players with [role = "PGOM"][set promo-safety-stock safety-stock-AHdc] ]         ;; here the safety-stok is again the regular safety stock of the AH DC (managed by PG OM)

   if first promoschedule = 1 and weekday = 1 and transparency = 1                        ;; also for PGSup agent the safety-stock during promotions is different to assure right replenishment.
    [ask players with [role = "PGSup"][set promo-safety-stock (promo-forecast - promo-forecast * 0.7) + safety-stock-PGdc]] ;; the safety stock during a promotion is set to a higher level: the regular safety stock + the 30% that is not yet produced for the promo
   if first promoschedule = 1 and weekday = 2 and transparency = 1                        ;; this will tigger promotion on the monday of the promotion week and will then thus produce the rest of the initial forecast
    [ask players with [role = "PGSup"][set promo-safety-stock safety-stock-PGdc]]

   if first promoschedule = 1 and weekday = 1 and transparency = 1                        ;; PG Dem has again the same calcylations as PGSup, with their 'virtual DC'
    [ask players with [role = "PGDem"][set promo-safety-stock (promo-forecast - promo-forecast * 0.7) + 80000]]
   if first promoschedule = 1 and weekday = 2 and transparency = 1
    [ask players with [role = "PGDem"][set promo-safety-stock safety-stock-PGdc]]
 ]


 if interconnectivity = 3[                                                                ;; this section determines the safety stocks during promotion weeks when the processes are fully aligned
   if first promoschedule = 1 and weekday = 1                                             ;; the section for Albert Heijn and the replenishment and ordering or their stores is not different from the section above
    [ask players with [role = "Albert Heijn"][set promo-safety-stock promo-forecast / 7 ]]
   if first promoschedule = 1 and weekday = 2
    [ask players with [role = "Albert Heijn"][set promo-safety-stock  (((promo-forecast * uplift) * 0.25) - promo-forecast / 7  + inventory-store)]]
   if first promoschedule = 1 and weekday > 2 and weekday <= 7[
    ifelse inventory-store >= safety-stock-store
     [ask players with [role = "Albert Heijn"][set promo-safety-stock inventory-store + (promo-forecast * uplift) / 7 * 0.75 * 0.4 ] ]
     [ask players with [role = "Albert Heijn"][set promo-safety-stock safety-stock-store + (promo-forecast * uplift) / 7 * 0.75 * 0.4 ] ]]
   if first promoschedule = 1 and weekday = 7
     [ask players with [role = "Albert Heijn"][set promo-safety-stock safety-stock-store] ]
   if first promoschedule < 1
    [ask players with [role = "Albert Heijn"][set promo-safety-stock safety-stock-store] ]


   if first promoschedule = 1 and weekday = 1
    [ask players with [role = "PGOM"][set promo-safety-stock promo-forecast * uplift / 7 + safety-stock-AHdc] ]          ;; this section is only different in the sense that it is not needed to determine a specific replenishment on the tuesday of a promo
   if first promoschedule = 1 and weekday = 7
    [ask players with [role = "PGOM"][set promo-safety-stock safety-stock-AHdc] ]]

   if first promoschedule = 1 and weekday = 1 and transparency = 1
     [ask players with [role = "PGSup"][set promo-safety-stock (promo-forecast * uplift - promo-forecast * 0.7) + safety-stock-PGdc]]
   if first promoschedule = 1 and weekday = 2 and transparency = 1
     [ask players with [role = "PGSup"][set promo-safety-stock safety-stock-PGdc]]

   if first promoschedule = 1 and weekday = 1 and transparency = 1
     [ask players with [role = "PGDem"][set promo-safety-stock (promo-forecast * uplift - promo-forecast * 0.7) + 80000]]
   if first promoschedule = 1 and weekday = 2 and transparency = 1
     [ask players with [role = "PGDem"][set promo-safety-stock safety-stock-PGdc]]

 end

 to update-safety-stock                                       ;; this function updates the safety-stocks of the various agents according to the specific week (thus preloads or promotions or regular weeks)
   if first butfirst promoschedule = 1 or first butfirst butfirst promoschedule = 1 [   ;; this section determines whether or not a preload or pre production is taken place
     ask players[
       if preload >= 0[                              ;; if the preload determined above is larger than zero, this will be used put into the model as a 'safety-stock' to trigger replenishment up to the level that the preload needs to be
         set promo-safety-stock preload]]]           ;; thus if there is a preload, the promo-safety-stock becomes the value of the preload.

   ask players with [role = "PGOM"][
     ifelse promo-safety-stock >= safety-stock[      ;; This promo-safety-stock information shell is then used to determine the relative safety stocks of the agents themselves.
       set safety-stock promo-safety-stock]          ;; Thus for PGOM the safety stock is set here to the promo-safety-stock if there is any in place.
     [set safety-stock safety-stock-AHdc] ]

   ask players with [role = "Albert Heijn"][         ;; The updating of the safety stock is the same for each agent.
     ifelse promo-safety-stock >= safety-stock[
       set safety-stock promo-safety-stock]
     [set safety-stock safety-stock-store] ]

   ask players with [role = "PGSup"][
     ifelse promo-safety-stock >= safety-stock[
       set safety-stock promo-safety-stock]
     [set safety-stock safety-stock-PGdc] ]

   ask players with [role = "PGDem"][
     ifelse promo-safety-stock >= safety-stock[
       set safety-stock promo-safety-stock]
     [set safety-stock 80000] ]
 end


 to calc-monday-demand-promo

   if first promoschedule = 1 and weekday = 1                 ;; this section calculates the monday demand during a promotion week. This is important, as this is used as to determine the uplift.
   [ifelse real-life-data = 0[                                ;; if real-life data is not used (thus zero), the hourly sales are randomly generated based on the forecast and uplift.
     ifelse hour > 8 and hour < 20[
       set monday-sales (floor random-normal (promo-forecast * (1 / 91)) (promo-forecast * 0.005) + monday-sales)
       if monday-sales < 0[
         set monday-sales 0] ]
     [if hour = 7[
       set monday-sales 0] ]
     set promotional-sales monday-sales ]

   [set promotional-sales (first forecast-realization) / 7]]  ;; if real-life data is used, the promotional sales on monday are just 1/7th of the forecast realization that is taken from historical data

 end

           to calc-hourly-demand-promo                        ;; this section calculates the hourly demand during a promotion week for the days tuesday till sunday. In the same way as for the monday calculations

             if first promoschedule = 1 and weekday > 1[
               ifelse real-life-data = 0[                     ;; if real-life data is not used (thus zero), the hourly sales are randomly generated based on the forecast and uplift
               ifelse hour > 8 and hour < 20[                 ;; it records hourly sales between 8 o'clock in the morning until 8 at night
                 set  promotional-sales (floor random-normal ((promo-forecast * (1 / 91)) * uplift) ((promo-forecast * 0.005) * uplift) + promotional-sales)
                 if promotional-sales < 0[
                   set promotional-sales 0] ]
               [if hour = 7[
                 set promotional-sales 0] ]
               set promotional-sales promotional-sales ]

              [set promotional-sales (first forecast-realization) / 7]]

             if weekday = 1 and hour = 7 [
               set promotional-sales 0]


           end

           to determine-uplift                                ;; this section calculates the uplift in a promotion week.
             if first promoschedule = 1 and weekday = 1 and hour = 18[
               ifelse real-life-data = 0[                     ;; this lines states that uplift is only calculated when no real-life data is used, the uplift is determined.
                 if monday-sales  < (promo-forecast * (1 / 7) * 0.85 * (11 / 13))[      ;; promo-forecast are the weekly sales, thus 1/7 is daily sales, and 11/13 is the amount of sales on monday until 18:00h in the afternoon
                   set uplift monday-sales / (promo-forecast * (1 / 7) * (11 / 13))]     ;; 0.85 determines that the an uplift is only calculated if the sales vary more than 15% from the forecast. Otherwise the uplift is set at 1 (the next line of code).

                 if monday-sales < (promo-forecast * (1 / 7) * 1.15 * (11 / 13)) and monday-sales > (promo-forecast * (1 / 7) * 0.85 * (11 / 13))[
                   set uplift 1]

                 if monday-sales > (promo-forecast * (1 / 7) * 1.15 * (11 / 13))[
                   set uplift monday-sales / (promo-forecast * (1 / 7) * (1 / 13))] ]

               [set uplift promotional-sales / (promo-forecast * (1 / 7)) ]]            ;; this line determines the uplift when real-life promotional data is used (then the promotional sales are used instead of the randomly generated monday sales.

             if first promoschedule < 1 [
               set uplift 1]
           end

           ;;----------------------------------------------;;
           ;; Update-timings for extra delivery in promoweek;;
           ;;----------------------------------------------;;

           to update-timings                                  ;; quite straightforward, this updates the process and place timings of orders during a promoweek when a monday afternoon release is in place
           if first promoschedule = 1 and weekday = 1 and hour = 15[
             ask players with [role = "Albert Heijn"][
               set process-time 18
               set place-time 19 ]

             ask players with [role = "PGOM"][
               set process-time 20
               set place-time 21]

             ask players with [role = "PGSup"][
               set process-time 21
               set place-time 22]
```

```
  ask players with [role = "PGDem"][
    set process-time 23
    set place-time 23]

  ask players with [role = "PGProd"][
    set process-time 13
    set place-time 13] ]

if first promoschedule = 1 and weekday = 2 [
ask players with [role = "Albert Heijn"][
    set process-time 6
    set place-time 9 ]

  ask players with [role = "PGOM"][
    set process-time 10
    set place-time 10]

  ask players with [role = "PGSup"][
    set process-time 11
    set place-time 11
    set pipeline-PGDem-PGdc 1]

  ask players with [role = "PGDem"][
    set process-time 12
    set place-time 12]

  ask players with [role = "PGProd"][
    set process-time 13
    set place-time 13] ]
end


to return-orders                                   ;; This function calculates the amount that needs to be returned from the Albert Heijn DC to the P&G DC after a promotion.
  let return-order 0

  if last promoschedule = 1 and weekday = 2 and hour = 0[
    set return-order inventory-AHdc - safety-stock-AHdc
    ask players with [role = "PGOM"][
      set inventory-AHdc safety-stock-AHdc]
    ask players with [role = "PGSup"][
      set inventory-PGdc inventory-PGdc + return-order]
  ]
end
```