Master Thesis

Supply Chain of Production Chemicals

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"Towards a synchronized coordination in the supply chain of Production Chemicals"

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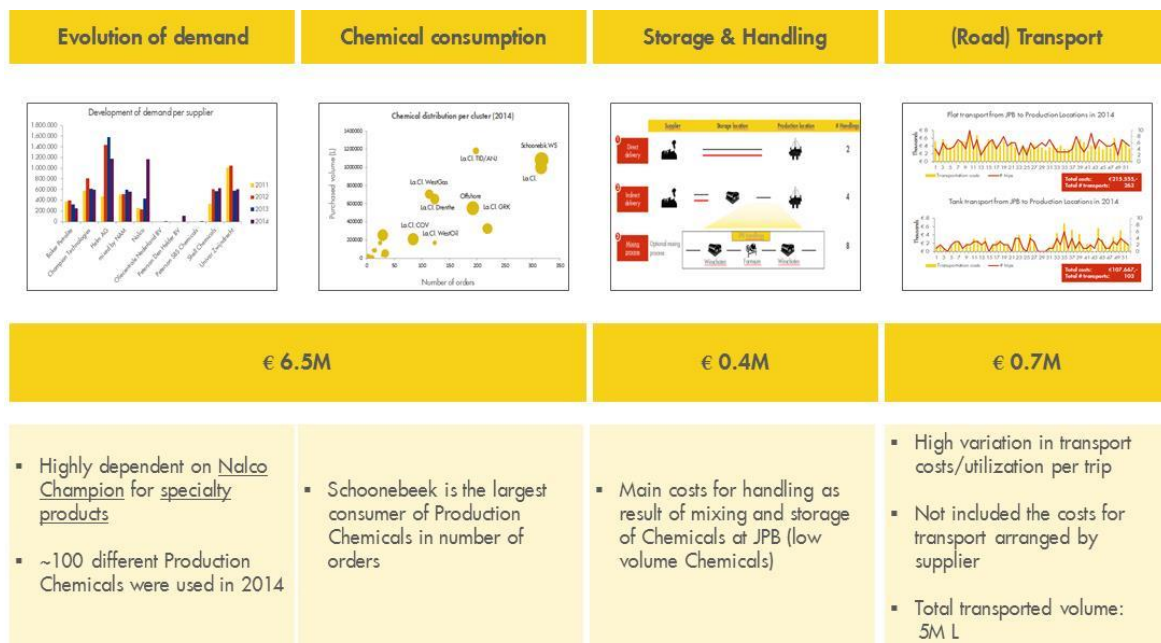Gerard.vandenBerg@shell.com

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Management Summary

This research is conducted at the Logistics Department of NAM (Nederlandse Aardolie Maatschappij). Production Chemistry, Contracting & Procurement and Operations are, besides Logistics, the most important stakeholders in the supply chain of Production Chemicals. The overall objective of this research is to generate a synchronized coordination of the roles and responsibilities throughout supply chain of Production Chemicals, in order to effectively deploy logistical resources. This objective is deduced from the cohesive sense of unease in the organization of Production Chemicals. We use a three phases approach to realize this objective:

1) Mapping the current way of working
2) Analyse the current situation to identify & rank inefficiencies
3) Conduct an optimization study to eliminate waste in the process

1) Mapping the current way of working: We first conduct thorough Data Analysis to get a feeling with the flow of Production Chemicals, which is summarized below.

Evolution of demand	Chemical consumption	Storage & Handling	(Road) Transport
	€ 6.5M	€ 0.4M	€ 0.7M
▪ Highly dependent on Nalco Champion for specialty products ▪ ~100 different Production Chemicals were used in 2014	▪ Schoonebeek is the largest consumer of Production Chemicals in number of orders	▪ Main costs for handling as result of mixing and storage of Chemicals at JPB (low volume Chemicals)	▪ High variation in transport costs/utilization per trip ▪ Not included the costs for transport arranged by supplier ▪ Total transported volume: 5M L

The Chemical Lifecycle consists of multiple phases. Production Chemistry already developed a Chemical Lifecycle, but this overview is specified to only the Production Chemistry department. After a critical review of the Chemical Lifecycle, we see three different phases in the organization of Production Chemicals: (i) Selection of Production Chemicals, (ii) Recurring ordering process, (iii) Monitoring of consumption.

The general overview of the organization is translated in a Roles & Responsibilities matrix (RACI-matrix). The matrix describes all steps in the supply chain of Production Chemicals, who is responsible for execution of the steps and which departments should be involved in these steps. Implementing the RACI-matrix in the Corporate Management System yields following benefits:

- Reduces misunderstandings
- Assigns accountabilities to each role
- Eliminates duplications of effort
- Improves understanding of cross-functional view of employees across divisions or departments

Overall, this RACI matrix prevents waste activities throughout the supply chain, which relates to the overall objective to deploy logistical resources effectively.

2) Analyze the current situation to identify & rank inefficiencies: We identify nine key issues in analyzing the current process. We address the issues along with their impact and department. In the light of this graduation research, we focus on the issue where my technical study background could add most value to the business. We also consider the urgency of the issues and the likelihood of implementing the solutions. We have therefore defined three potential optimization studies regarding issues 6, 8 and 9. The objective and characteristics of these optimization studies are illustrated below.

6	**8**	**9**
Reduce transport costs by changing injection facilities	**Optimize inventory management at central storage lcoations**	**Increase capacity utilization in transport of Production Chemicals**
Annual costs: €700,000.-	*Annual costs: €70,000.-*	*Annual costs: €700,000.-*
• High investment costs from Operations to change storage equipment or packaging materials	• Requires a consumption forecast of multiple months • Relatively low financial benefits • Applicable to only one storage location • Increase in reliability of delivery	• Requires a consumption forecast of a few weeks • Supports both Logistics and Operations in daily work • Significant financial benefits Reduces number of physical checks at injection locations

We discuss the potential optimization studies with the project stakeholders. The conclusion of our discussion is to focus the remainder of this graduation project on increasing capacity utilization in transport of Production Chemicals (issue 9).

3) Conduct an optimization study to eliminate waste in the process: The objective for the optimization study is to minimize total duration of the replenishment cycle of supplying Chemical Injection locations in Intermediate Bulk Containers (IBCs). In order to realize this objective, we developed a Chemical Distribution Model for the Planning Cell which automatically generates a replenishment schedule for area North. This Model enables the Planning Cell to move from a reactive scheduling process to proactively proposing schedules to the clients. A combination of Rolling Horizon Planning and Travelling Salesman Problem is used to develop the algorithm behind the Model. Especially with the addition that each location may, or may not be visited makes this variant of Traveling Salesman Problem to the best of our knowledge.

We use the Chemical Distribution Model for every week in the second half of 2014, to calculate potential benefits of this model. The model proves to deliver valid Chemical replenishment schedules, assuring sufficient Chemical inventory levels at any time. The simulation study indicates a reduction of around 29% in transport costs, comparing the results with actual transport data in 2014. Annual costs reduction yields €25,000 in replenishment of Production Chemicals to the Northern part of the Netherlands. Next to the financial benefits, the proactive approach in replenishment of Production Chemicals also:

- Prevents gas deferments by minimizing the out of stock probabilities at injection locations
- Eliminates Rush Orders
- Reduces number of visits to (unmanned) injection locations for physical inventory checks

Furthermore, recommendations are provided for implementation of the deliverables and to eliminate the concerns regarding the other issues. Figure below illustrates the most important recommendations, together with the responsible department and level of implementation effort.

Implementation effort	Logistics	Production Chemistry
High	Define a clear procedure to manage inventories throughout the supply chain	Start Quality Assurance/Quality Control of delivered Production Chemical mixes
	Implement Chemical Distribution Model and also develop for Area West	
Low	Add RACI-matrix to the Corporate Management System	

Department

Contents

1. Introduction

In the framework of completing my Masters Industrial Engineering & Management at the University of Twente, I conducted my graduation thesis at Nederlandse Aardolie Maatschappij (NAM). This research focuses on the supply chain of Production Chemicals within the leading natural gas and oil producer of the Netherlands, the NAM. Productivity of the gas and oil fields reduce as the oil and gas fields age. In order to enhance and maintain production, the NAM can either drill new production wells, or inject Production Chemicals to existing wells. A wide variety of those Production Chemicals have been introduced over the years, each having a different purpose for stimulation of production. Nowadays, many production locations are not even able to operate without specific chemicals. The recent shift towards 'green chemicals' increases the variety of chemicals used, amplifying the complexity of the supply chain.

Chapter 1 provides an introduction to the research. Section 1.1 introduces the organization with a brief description of the company, and related department. Section 1.2 clarifies the motivation for the research. Section 1.3 describes the problem, followed by the project scope in Section 0. Section 1.5 explains the research goal, and Section 1.6 provides the research questions. We would like to conclude Chapter 1 with the research approach in Section 1.7.

1.1   Company description

Nederlandse Aardolie Maatschappij (NAM) is a joint venture of Shell (50%) and ExxonMobil (50%) and was founded in 1947. Core business of NAM is exploring for and producing oil and gas, both on land and offshore in the Netherlands and on Southern North Sea. NAM is the leading natural gas producer in the Netherlands, accounting for 75% of the total Dutch demand for natural gas. The oil production of NAM accounts for one fifth of the oil produced in the Netherlands. NAM employs over 1700 staff and has its headquarters in Assen.

Project's promoter is the logistics department, which supports production of the assets throughout the life cycle by timely identification, coordination and reliable distribution of sustainable logistics expertise and resources, in particular:

- Distribution and storage of Production Chemicals
- Transport of people and goods
- Lifting and Hoisting
- Load / Distribution
- Industrial cleaning
- Waste management

High attention is paid to safety regulations for all services provided by the Logistic department. The department aims to provide cost-effective delivery of services. To reduce waste in logistics, the Logistic Excellence section has been established to support, improve and optimize the processes and apply innovative solutions where these add value to the end users.

1.2   Motivation

Decreasing trends in oil and gas prices and upcoming challenges to enhance or maintain oil and gas production in the Netherlands stress out the importance of being cost-effective. In further improvement of the logistic activities, the Logistics Department established the Logistics Excellence section in December 2014. Professionals in this section of the Logistics Department are continuously supporting, improving and optimizing the logistical processes. One of the subjects to analyze is the flow of Production Chemicals.

Usage of chemicals has exploded over years, raising the acquisition costs for raw chemicals up to €6M in 2014. The chemical streams did not only increase in volume, it also broadened in variety. The production chemicals are, to a greater or lesser degree, marked as dangerous and hazardous goods, requiring extra measures for handling and packing of chemicals. The historical growth in demand of production chemicals together with legal issues for chemical handling have led to a complex supply chain for Production Chemicals. The supply chain evolved historically, but has not been fully analyzed ever since.

Aiming at the facilitation of operational activities and a reduction of costs due to decreased oil prices, the Logistics Excellence section is triggered to thoroughly understand the supply chain of Production Chemicals. Thorough understanding of the supply chain facilitates the collaboration and synchronization of tasks between different stakeholders in the process. Furthermore, the understanding enables us to analyze the supply chain and indicate the opportunities for optimization and cost savings.

1.3   Problem description

The NAM currently faces fragmented coordination in the supply chain of Production Chemicals, which hinders the identification and removal of inefficiencies in the supply chain. The lack of coordination and understanding makes the Logistics department relying on the experience of the planning and administration cell for Production Chemicals. Looking at the bigger picture, we see that roles and responsibilities of different stakeholders in the process are blurred as well. Consequently, the stakeholders are not able to take the interests of stakeholders in other departments into consideration and are mainly focused on their own tasks. The problem statement is as follows:

"Fragmented coordination of the Production Chemicals' supply chain, and unidentified roles, responsibilities of the different stakeholders in the process"

Due to the historical growth of demand in production chemicals, the Logistics Excellence section is questioning the efficiency in the process of Production Chemicals. Based on the transparent overview of the supply chain, as well as the roles, responsibilities and interests of different stakeholders, the waste could be identified. Hypotheses 1 is therefore:

"Fragmented coordination of the Production Chemicals' supply chain, and unidentified roles, responsibilities of the different stakeholders in the processes lead to ineffective deployment of resources in the supply chain of Production Chemicals"

1.4   Research scope

This research concerns the chemical flow used to enhance and maintain oil and gas production in the Netherlands and the Southern North Sea. The flow of chemicals returned are outside the scope, as are chemicals used for other purposes than stimulation of production (e.g. drilling), or chemicals used in different geographic regions. To define the scope of the project, this research comprises three phases.

Phase I: Map the current way of working

This research defines the roles, responsibilities and interests of stakeholders regarding the supply chain of Production Chemicals in the Contracting & Procurement, Production Chemistry, the Logistics departments and for Operations. We provide recommendations to improve coordination between the different departments.

The supply chain of Production Chemicals is expressed in terms of information, materials, and cash.

Figure 1.1 Flow of Production Chemicals

The supply chain of chemicals is mapped from procurement of (raw) chemicals until the delivery of the chemicals at the production location and all processes in between. So, we map all movements from the moment we are in charge of the chemicals until delivery at the production location (which can be seen as client).

In order to provide clear insights in the complex supply chain, we divide the supply chain in three main categories; *material management flow, capacity management and physical packaging*. Following data is gathered to provide insights in the information, cash and material flows of Production Chemicals:

1. Material management flow	2. Capacity management	3. Physical packaging and mixing
▪ Chemical consumption ▪ Distribution network from supplier to production location ▪ Contractors used ▪ Forecast Chemical demand	▪ Used resources (e.g. IBCs, IMUs, Containers, trucks) ▪ Stock/storage usage	▪ Mixing of chemicals ▪ Repackaging of chemicals

Table 1.1 Data collection

The Production Chemicals flow in the Netherlands and OGE (ONEgas East) Southern North Sea is managed from NAM's headquarter in Assen.

Phase II: Analyze the current situation to identify and rank inefficiencies

Thorough analysis of data and information collected in Phase I, helps us to identify (in)efficiencies in the supply chain of production chemicals. In scope of the analysis are the process and data collected in Phase I.

Phase III: Conduct an optimization study to eliminate waste in the process

Due to time constraint of six months, scope is narrowed in Phase III to one part of the chemical flow, having the highest improvement potential. Considering restrictions of the University, the optimization study focuses on the supply chain, rather than redefining the roles and responsibilities. Outside scope of supply chain optimization are; the contract arrangements for chemicals, the selection of preferred supplier, as well as the volume of chemicals to be injected.

1.5   Research goal

We have defined two problems in section 1.3. First problem is that the chemical flow lacks transparency in stakeholders and supply chain. Due to lack of transparency, we assume that mapping this complicated supply chain of chemicals reveals some inefficiencies in deployment of resources, which are being tackled subsequently. So, the goal of the research is to:

"Generate a synchronised coordination of (roles and responsibilities in) the supply chain of Production Chemicals resulting in maximal value added services from an end-user perspective"

1.6   Research question

This research focuses on transparency in the complete supply chain of Production Chemicals on the one hand, and optimization of a specific chain in the supply of Production Chemicals on the other hand. To be able to achieve these goals, we have defined the following research questions:

1. *What does the current situation look like, how is it controlled and what are the supply chain characteristics?*
    - *Which suppliers are involved in the supply of raw chemicals?*
    - *Who, what and where are the different chains in the distribution network?*
    - *What types of transportation are used?*
    - *What types of packaging materials are used?*

    An overview is provided to understand the processes and stakeholders in the supply chain of Production Chemicals, from procurement to usage in production.

2. *How did the supply chain evolve between 2011-2014?*
    - *In terms of material flows?*
    - *In terms of capacity usage?*
    - *In terms of physical packaging transactions?*

    The supply chain and its characteristics are explained in processes and with the support of actual transaction data between 2011 – 2014.

3. *Who are the stakeholders and what are their roles, responsibilities and interests in the Production Chemicals flow per department?*
    - *Logistics department*
    - *Production Chemistry*
    - *Contracting & Procurement*
    - *Operations*

    A descriptive matrix is displayed per department with relevant information per stakeholder.

4. *Where in the supply chain could we identify potential improvements?*
    - *Materials management flow: What, when, how much and from where to order?*
    - *Physical packaging/mixing: (Re)packaging and mixing of chemicals during supply chain (e.g. bulk-bulk, bulk-mix-container)?*
    - *Capacity management: Usage of containers/tanks/IBCs/IMUs, trucks, storage?*
    - *Transportation: Routing problem?*
    - *Combination of previously described problems in the supply chain?*

    Analysis of the data helps us to identify the opportunities to optimize (part of) the supply chain. The problem with highest improvement potential is chosen as optimization problem for this research.

5. *Which methods for the optimization problem[1] could we find in the literature?*
6. *What are the suitable optimization models to use?*
7. *How could we model and improve the optimization problem?*
    A model is designed to optimize the identified problem.

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[1] The problem to optimize follows from research question 4: *Where in the supply chain could we identify potential improvements?*

8. *What steps need to be taken to move from current situation to the desired situation?*
Developing an implementation plan for the proposed solution.
9. *What are the benefits of the designed model?*
Defining the benefits of the new model in terms of financial improvement potential, required resources, impact on environmental footprint.

1.7   Research approach

Section 1.7 outlines the research approach. First, we determine the Production Chemicals flow, predict the development of Production Chemicals' demand, and analyze the supply chain in Chapter 2. This information is obtained from internal data sources and interviews with the Logistics department, responsible for the planning. Conducting interviews with representatives from all departments involved in the Production Chemical Lifecycle gives us an overview in the roles and responsibilities of the stakeholders, which is displayed in Chapter 3. In Chapter 0, we evaluate the identified improvement areas and define the research focus by discussing the potential impact with the key representatives during group meetings. We conduct a literature research to find suitable models used as input for the solution design in Chapter 5. The solution design for the optimization problem is developed in Chapter 6 and consists of an integer linear programming model. Due to restricted software availability, we are forced to program the model in Excel rather than the more convenient tools as AIMMS or OMPL. Chapter 0 elaborates on the data required for the solution design. We import data from different data sources and in order to fully rely on this data, we automatically modify the input data in the Model. Chapter 0 provides a simulation study to define the potential benefits of the solution design. An implementation plan for the solution design is described in Chapter 9, which is also discussed with end users of the solution design. Based on the outcome of this research, we end with conclusions and recommendations in Chapter 10.

2. Data analysis

Chapter 2 describes the current supply chain of Production Chemicals within the NAM. Section 2.1 provides an overview of the different Production Chemicals and their effects. Section 2.2 shows how Chemical demand has evolved between 2011-2014. Section 2.3 reveals data of Chemical consumption at injection locations in 2014. Section 2.4 briefly discusses the packaging materials used to deliver Production Chemicals to injection locations. We describe the modes of transport and transport movements for Production Chemical distribution in Section 2.5. This chapter concludes with an overview of storage and handling locations used for Production Chemicals in Section 2.6. Figure 2.1 illustrates some key findings of the data analysis.

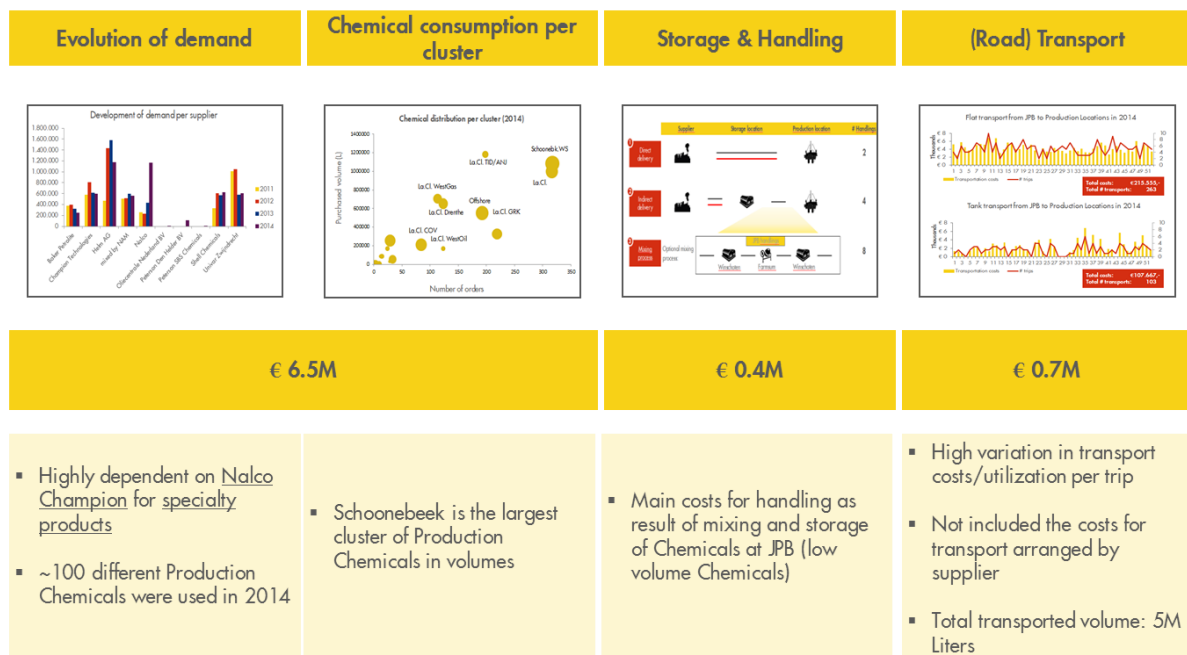| Evolution of demand	Chemical consumption per cluster	Storage & Handling	(Road) Transport
	€ 6.5M	€ 0.4M	€ 0.7M
▪ Highly dependent on Nalco Champion for specialty products ▪ ~100 different Production Chemicals were used in 2014	▪ Schoonebeek is the largest cluster of Production Chemicals in volumes	▪ Main costs for handling as result of mixing and storage of Chemicals at JPB (low volume Chemicals)	▪ High variation in transport costs/utilization per trip ▪ Not included the costs for transport arranged by supplier ▪ Total transported volume: 5M Liters

Figure 2.1 Production Chemicals at a glance

We have decided to analyze the Production Chemical flow in terms of volume, since this is most important driver for Logistics expenditures. The data analysis is based on a combination of Procurement data, Ordering data from Operations, Chemical mixing data, Transportation data and Storage data. The desired data was acquired from different databases, making it rather complex to analyze and link the data. We have indicated several inconsistencies in acquired data. Production Chemical volumes appear in different measures (e.g. Liters, KG, Tones, Trucks), making it difficult and time consuming to analyze data. It is also hard to link data from separate files, since a uniform key is missing (e.g. Procurement data and transport data is impossible to match).

Database	Information
Procurement data	Purchased volumes of Production Chemicals from suppliers, ordered by Planning Cell
Ordering data	Requested volumes of Production Chemicals from Production Locations
Transportation data	All flat and bulk transport which has been ordered by Planning Cell
Storage data	Invoices per central storage location (e.g. JPB)
Mixing data	Invoices of JPB

Table 2.1 Data sets

7

2.1 Production Chemicals

Section 2.1 describes the different types of Production Chemicals which are used in 2014. As already mentioned in the introduction, Production Chemicals are injected into from injection points to stimulate production of oil and gas, or to protect the equipment (pipelines). Production Chemicals are only used when no other opportunities can be applied to enhance production, or to protect equipment. Several Production Chemicals are injected, with different characteristics and effects. In Table 2.2, one can find the different Product Groups with its effects, used in 2014.

Product group	Function
H2S Scavenger	Binds H2S from gas phase into the produced liquids
KHI - Methanol	Causes decomposition of gas hydrates and prevents liquids from freezing – mainly DEG
KHI - Glycol	▪ Used to dehydrate natural gas – TEG ▪ Used to prevent crystallization in the well – MEG
Corrosion inhibitor	Reduces the corrosiveness of the produced fluids ▪ Most of the inhibitors are used as CO2 inhibitors
Sodium hydroxide	Used to extract low pH liquids from a well
Scale inhibition	Reduces or avoids precipitation of solids (halite, sulphates, carbonates, sulphides)
Liq Unloading	Liquid Unloaders causes foam formation until the well and reduces the critical gas velocity to lift fluids to the surface
Demi water	Used during the mixing process to create optimal substance of chemicals
Demulsifier	Breaking of emulsions (mixtures) of water and oil/condensate
Foamer	Reduces the hydrostatic pressure drop in a liquid loaded well
Defoamer	Breaking the foam to avoid carryover of liquids
Hydrate inhibition	Used to prevent crystallization in the well

Table 2.2 Poduct Groups

2.2 Chemical demand

Section 2.2 summarizes the Production Chemical demand of the NAM between 2011 – 2014. The different Product Groups are ordered from multiple suppliers, which can be found in the Appendices. Two of NAMs largest Chemical suppliers, Nalco and Champion Technology, merged recently. The NAM should be aware that it now heavily depends on one organization for specialty products, since Nalco Champion is the key supplier for specialty Chemicals. The NAM ordered Production Chemicals from 9 different suppliers between 2011 – 2014. Total demand for Production Chemicals over these years rose with 43% up to 5.1 million Liters in 2014. below, one can find the graphical representation of the evolution in demand between 2011 – 2014.
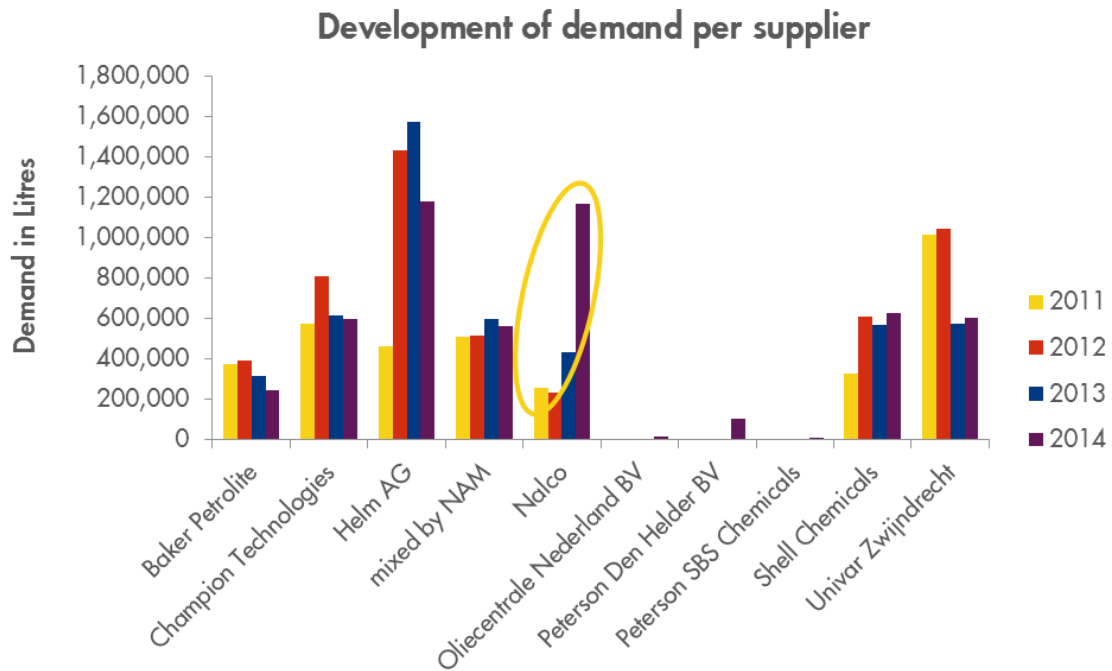
Development of demand per supplier

Figure 2.2 Chemical demand per supplier between 2011 - 2014

+ 43%

Production Chemicals	2011	2012	2013	2014
Total purchased volume (L)	3,569,156	5,095,194	4,707,260	5,122,811
Total purchasing costs	€ 5.2 M	€ 6.0 M	€ 5.6 M	€ 6.6 M

Table 2.3 Chemical demand between 2011-2014

The heavy increase in demand is mainly caused by the rise of the H2S Scavengers from Nalco and Methanol from Helm AG. Other Product Groups have shown less significant ups and downs in their demand over the last 4 years.

Evolution of demand in terms of volume
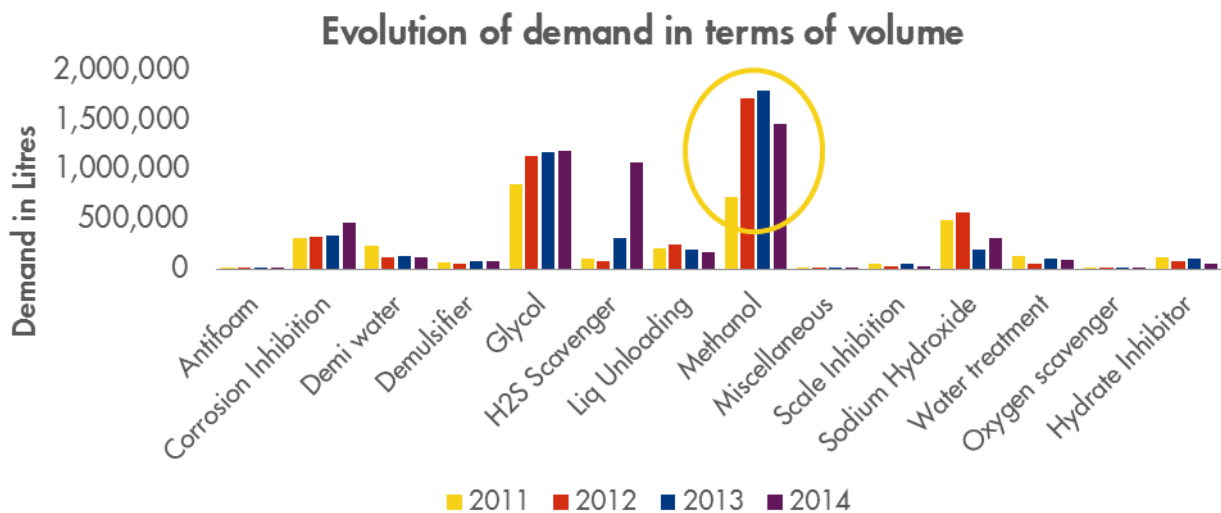
Figure 2.3 Chemical demand per Product Group between 2011 - 2014

From the data in Figure 2.4, we can see that in most cases, multiple suppliers are being used for the same Product Groups. This may be a strategic decision to spread risks and to ensure long term supply of Production Chemicals. If there is no strategic decision to use multiple suppliers for one Product Group, volume discounts may be realized using one supplier for each Product Group.

Suppliers per Product Group (2014)

4 different suppliers for Methanol

Legend: Baker Petrolite, Champion Technologies, Helm AG, mixed by NAM, Nalco, Peterson Den Helder BV, Peterson SBS Chemicals, Shell Chemicals, Univar Zwijndrecht
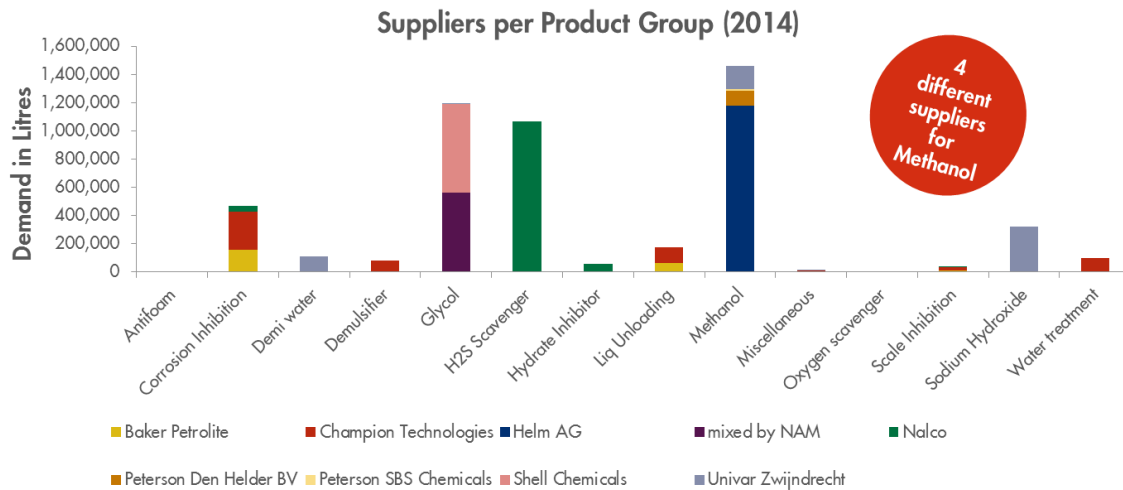
Figure 2.4 Portfolio of suppliers

In addition to the observation that multiple suppliers are being used per Product Group, we also identified many different types of Production Chemicals per Product Group. In total, 98 different types of Production Chemicals were used in 2014, for 14 Product Groups.

Production Chemicals per Product Group (2014)

98 different Production Chemicals were used in 2014

Antifoam: 1, Corrosion Inhibition: 24, Demi water: 3, Demulsifier: 7, Glycol: 13, H2S Scavenger: 2, Hydrate Inhibitor: 2, Liq Unloading: 4, Methanol: 5, Miscellaneous: 5, Oxygen scavenger: 2, Scale Inhibition: 9, Sodium Hydroxide: 2, Water treatment: 7, Others: 12
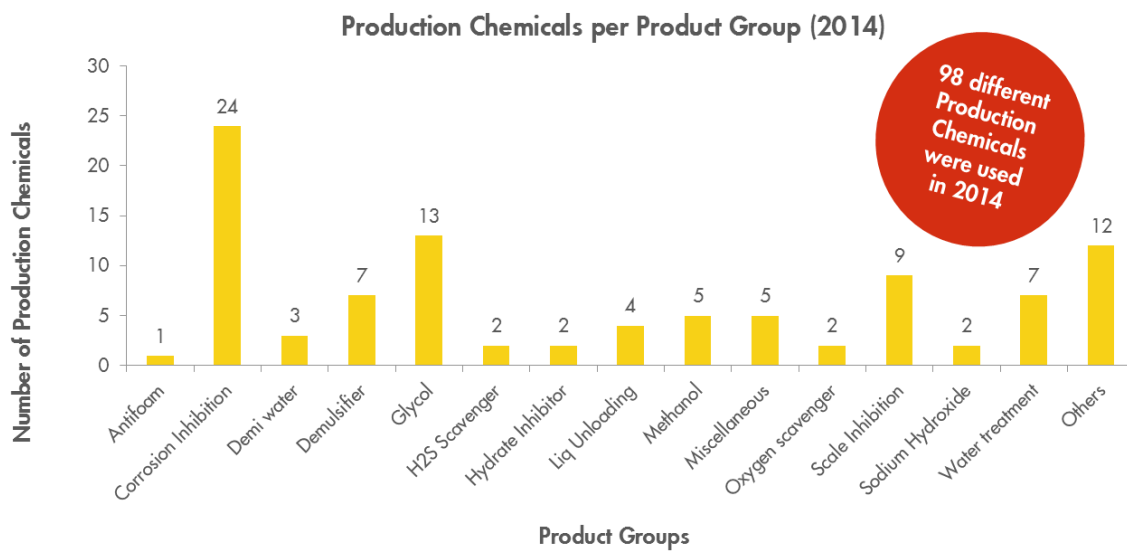
Figure 2.5 Types of Chemicals per Product Group

2.3 Consumption

The NAM distributes Production Chemicals to over 150 locations in the Netherlands and Southern North Sea. Each location could be assigned to one of the fifteen geographical clusters. Chapter 2.3 generates an overview of Production Chemical consumption on cluster level. below, one can find the geographical locations of the clusters within the Netherlands. Figure 2.7, shows the demand of Production Chemicals per cluster. Clusters Wildervank/Vries and Schoonebeek West are the most frequent 'customers' with 320 orders in 2014. Cluster Tytjerksteradeel/Anjum ordered almost 1.2 million Liters in 2014, but the number of orders is significantly less. The average volume per order from Tytjerksteradeel/Anjum is relatively high compared to other clusters. The expectation is that highest potential for (transport) optimization can be found at clusters with high frequency of orders and low average order volume.

Figure 2.6 Different clusters within the NAM
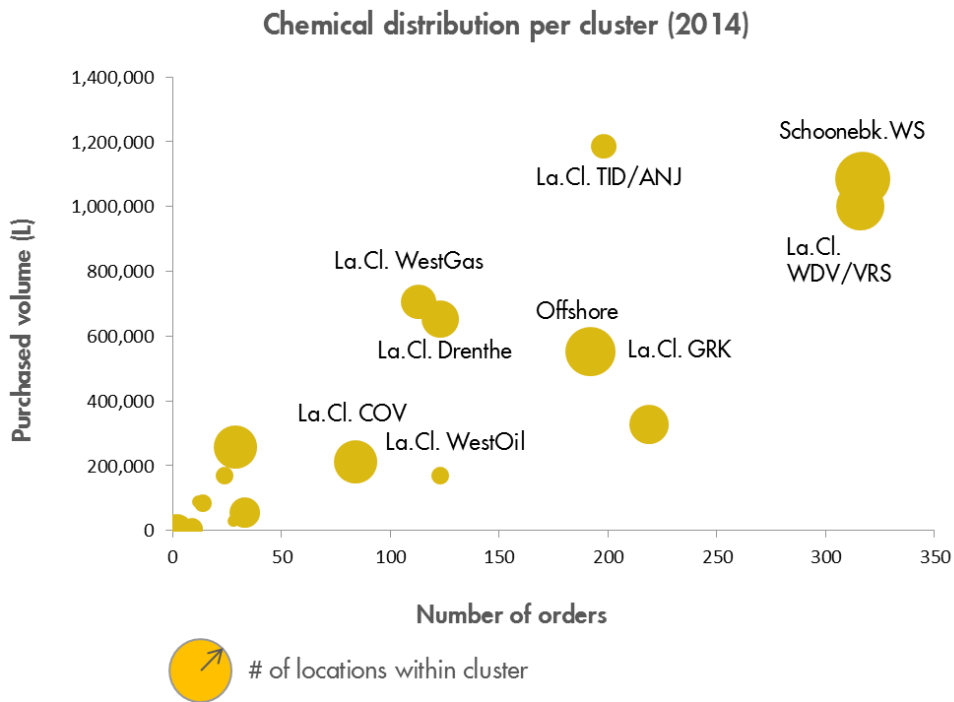
Figure 2.7 Chemical distribution per cluster

We can see from distribution of Production Chemical demand in Figure 2.8, that clusters inject multiple types of Product Groups in their wells. Corrosion Inhibitors are being used in almost all clusters and all clusters ordered at least three different types of Corrosion Inhibitors.
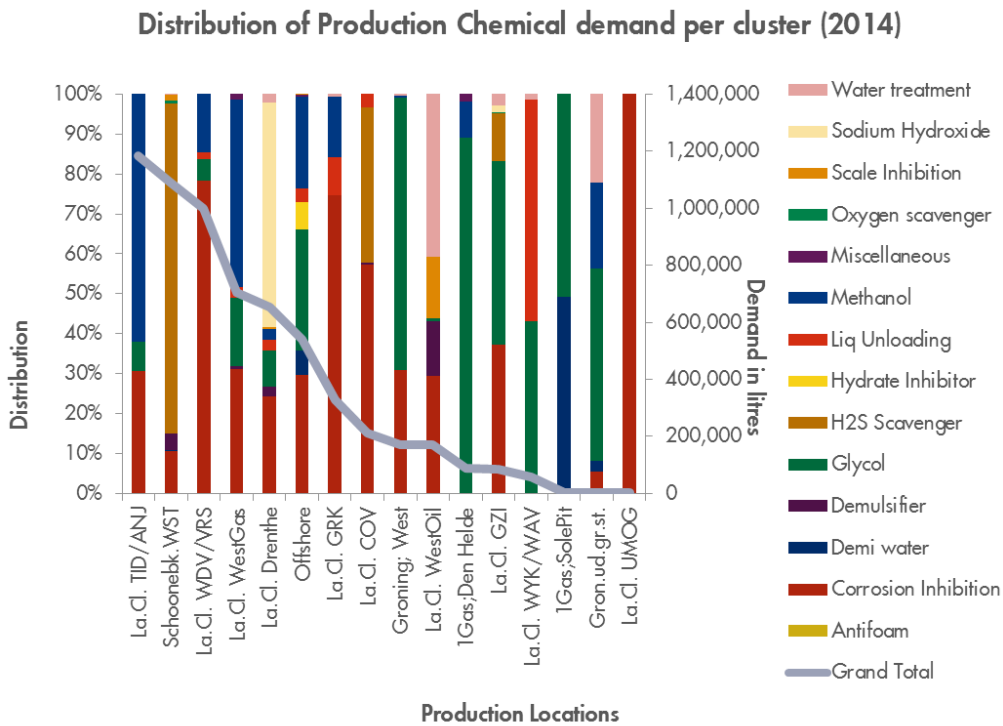
Figure 2.8 Distribution of Product Groups per cluster

2.4 Packaging materials

Requests from injection locations differ in Chemical types, in volumes and in concentrations of Production Chemicals. Section 2.4 elaborates on the different types of packaging materials used to replenish injection locations.

Equipment for storage at injection locations may differ per injection point. Fast running products, for example, most likely have storage capacity of at least 6 m^3. On the other hand, injection points with lower injection rates have less storage capacity. The type of storage equipment to be bought for an injection locations depends on expected injection volumes. The type of equipment influences the packaging material which is used to replenish injection locations. Several packaging materials are introduce to satisfy equipment constraints and to replenish injection locations most efficiently. The different types of packaging material are (See Appendices for detailed information):

- Bulk
- IBC
- IMOs
- Drums
- Cans
- Bottles

72% of all Production Chemicals is delivered in bulk, while most requests for Chemicals are related to IBCs. As we can see from Figure 2.9, average volume of a bulk order is more than 5 times as high as for IBCs. Overall, most of the orders are delivered processed in IBCs or in Bulk.
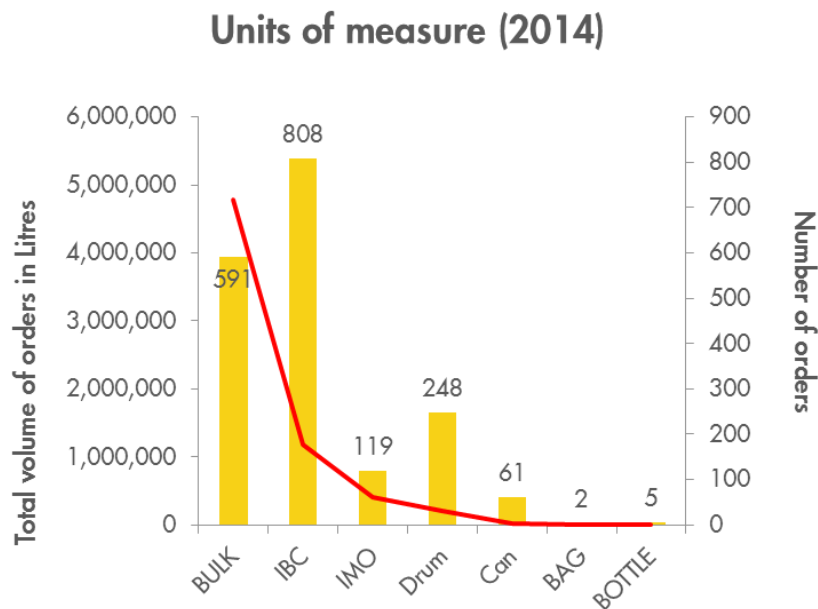
Figure 2.9 Packaging materials

	Bulk	IBC	IMO	Drum	Can
Average value of order	€ 5,608	€ 2,533	€ 3,213	€ 849	€ 745
Average volume of order (Litres)	8,598	1,455	3,402	825	226
Average costs per Litre	€ 0.69	€ 1.74	€ 0.94	€ 1.03	€ 3.29

Table 2.4 Quantities per packaging material

Packaging material for distribution is more or less similar for all clusters, except for the offshore locations. These locations are supplied by Production Chemicals in IMOs, which are specially designed for Offshore transport. Details about packaging material per cluster can be found below.
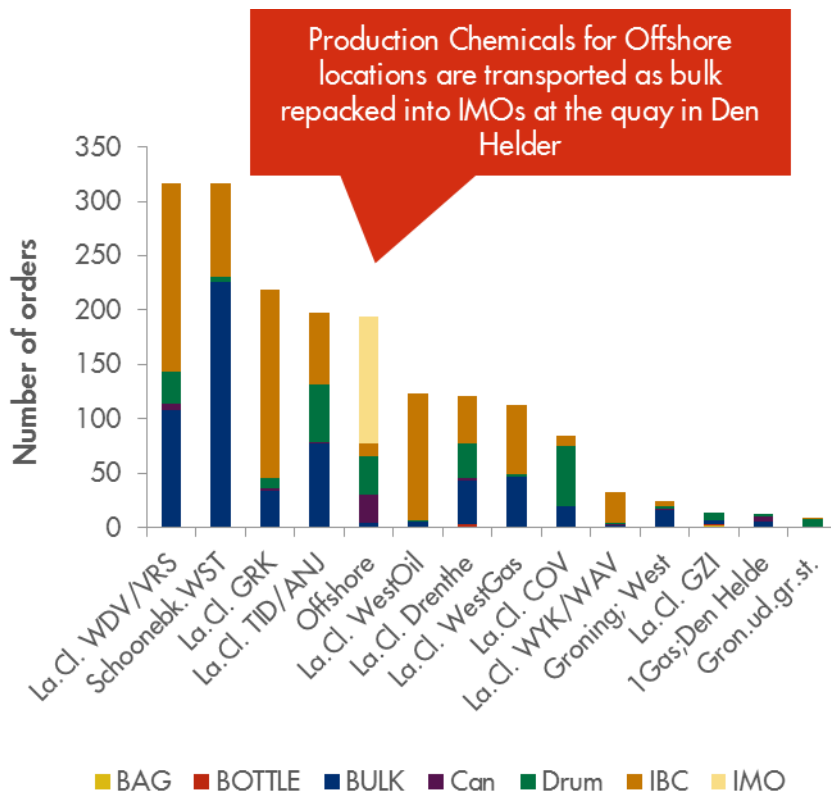
Figure 2.10 Packaging materials per cluster

2.5 Transport

Section 2.5 provides an overview of all transport movements related to Production Chemicals in 2014. Transport of Production Chemicals is managed by either the supplier, or by the NAM. The ownership of transportation differs per supplier and depends on the contract conditions arranged by the Contracting & Procurement department. Three types of transport are used for Production Chemicals:

- Tank transport
- Flat transport
- Vessels (for offshore supply)

The Logistics Department of the NAM is not responsible for the planning process of Vessels. We found out that it is rather difficult to analyze Vessel transport, so this is out of scope in Section 2.5.

Tank and flat trailers are used for road transport of Production Chemicals. Average total costs of a Trailer Tank trip to replenish Production Chemicals inventory is €965.-. Total costs for Trailer Tank transport was almost €500,000.- in 2014, divided over 487 different trips.
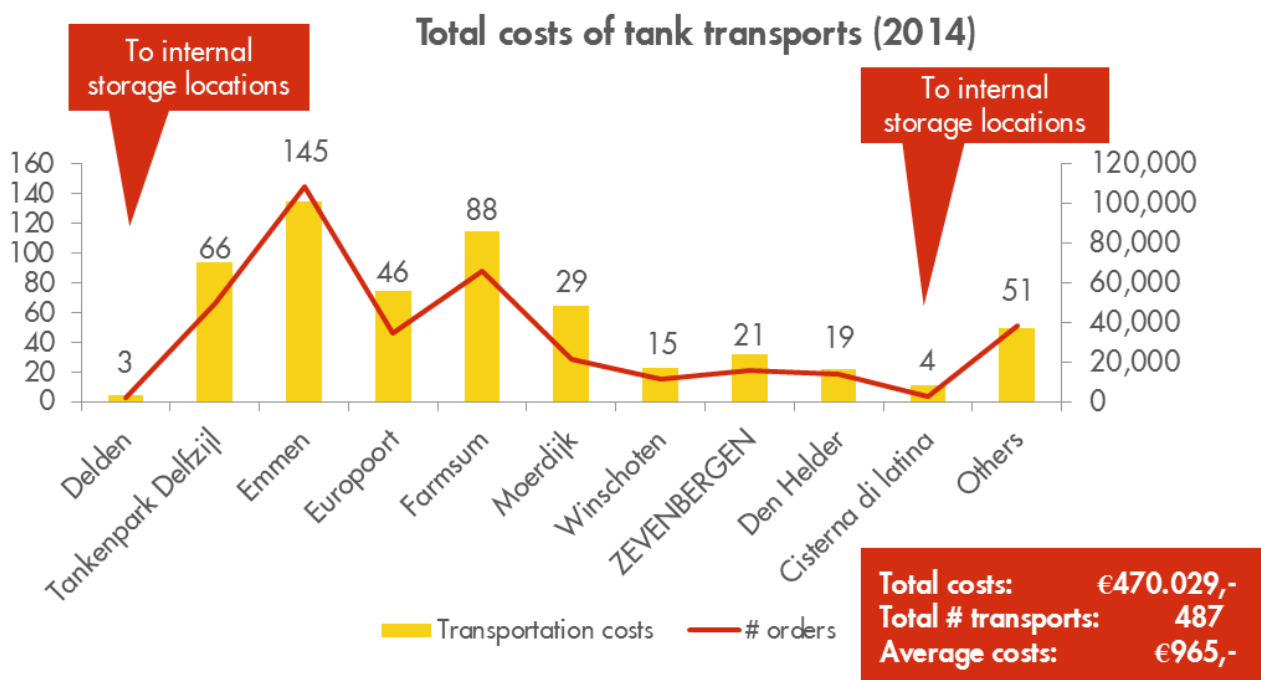
Figure 2.11 Total costs of tank transport per departure

Flat transport is used to distribute Production Chemicals in low batches (<1000 L) from the storage location JPB to the Production wells. On average, 5 trips a week are scheduled to deliver low volume batches of Production Chemicals to the Production wells. Occasionally, Flat transport to sections West Gas and West Oil make a detour to Champion Technology in Geertruidenberg to pick up Production Chemicals, or Flat transport occurs to transport low batches of Production Chemicals from supplier Univar in Zwijndrecht to JPB. We only present Flat transport from JPB, since occurrence of other trips is low and total costs of these trips are negligible. All transport from JPB is allocated to replenishment of injection locations.

Flat transport from JPB to Production Locations in 2014

Total costs: €215.555,-
Total # transports: 263
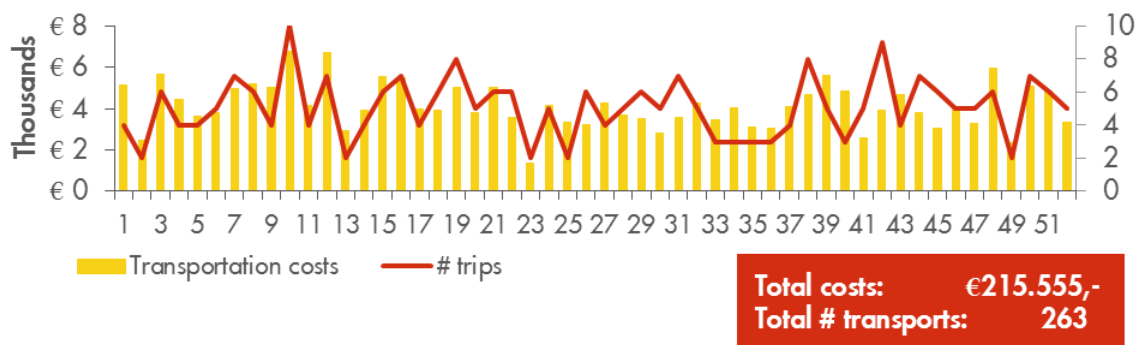
Figure 2.12 Flat transport from JPB per week

We also analyzed the Tank transport from JPB to the injection locations, see Figure 2.13. There is stronger correlation between number of trips and associated transportation costs for tank transport. The average costs of Tank transport are always near €1000.- per trip, while the average costs of Flat transport shows more fluctuations, as one can see in Figure 2.12. These fluctuations are caused by differences in capacity utilization of trucks and distances between different locations, since trucks are expensed per hour.

Tank transport from JPB to Production Locations in 2014

Total costs: €107.667,-
Total # transports: 103
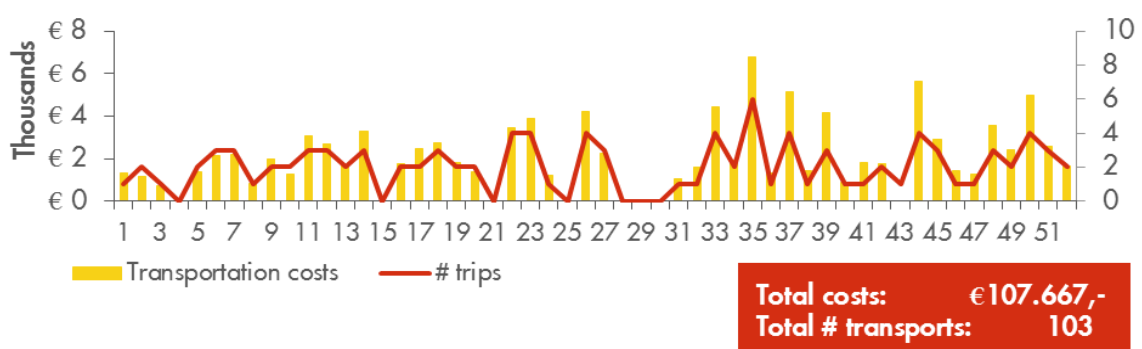
Figure 2.13 Tank transport from JPB per week

16

Planning Cell aims to schedule Flat transport on Wednesday and Thursday during the so called 'weekly IBC trips'. The weekly IBC trip is used to replenish injection locations and the traversed route depends on visited locations. Data analysis supports the occurrence of weekly IBC trips. We see peaks in trips on Tuesday and Wednesday. For the weekly IBC trip, a truck is loaded on Tuesday at JPB and replenishes the injection location on Wednesday. The costs for this trip are allocated to the Tuesday. The second IBC trip to the West of the Netherlands starts on Wednesday and ends on Thursday. These costs are always allocated to the Wednesday. Besides the weekly trips on Tuesday and Wednesday, we could also identify IBC trips on other days. These trips are aimed to replenish remaining injection locations due to under capacity of a truck, or caused by rush orders. As we can see from the analysis, average costs of irregular transports (e.g. Monday and Friday) are lower, since less time is needed to conduct the trip.

We assume from this data that there is potential to improve truck optimization and to reduce the number of trips. Full utilization of truck capacity reduces total costs of transport.

Flat transport from JPB to Production Locations in 2014

Total costs: €215.555,-
Total # transport: 263
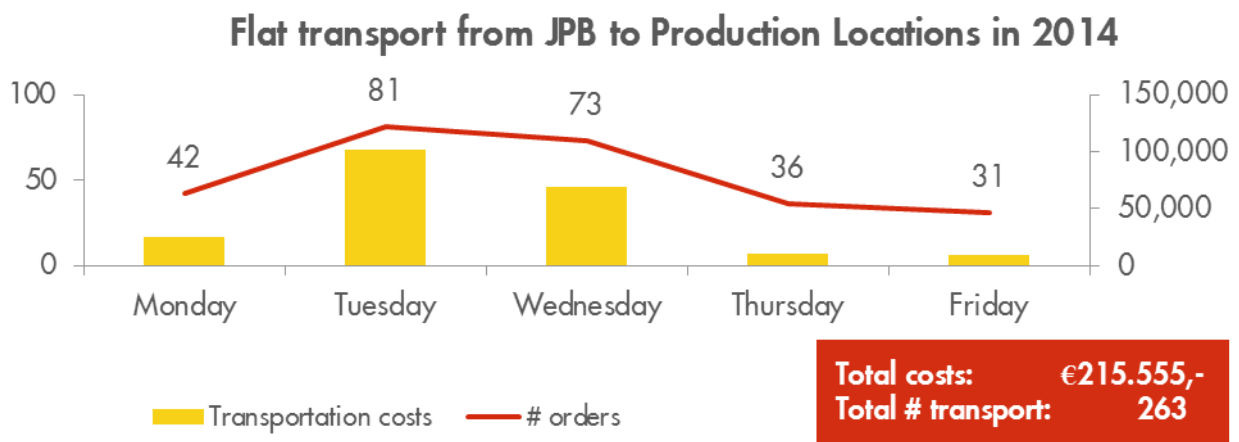
Figure 2.14 Number of trips for flat transport

Average costs of flat transport Production Locations in 2014

Total costs: €215.555,-
Average value: €820,-
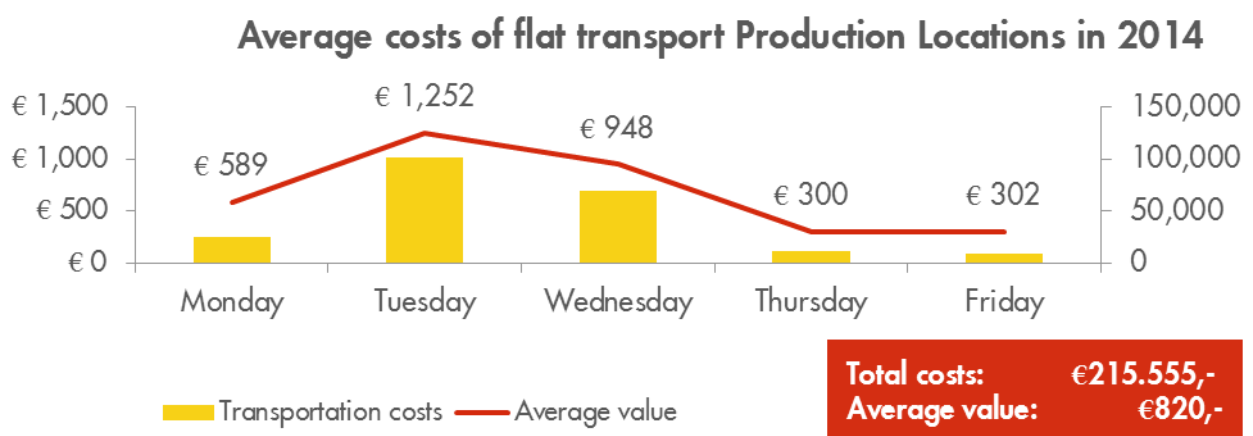
Figure 2.15 Average costs of flat transport

The contracts with suppliers include arrangements about the handover of ownership of Production Chemicals. There are three types of contract arrangements: Pick up Chemicals from supplier (Ex Works), Delivery to central storage location (Delivered Duty Paid), or Delivery to injection location (Delivered Duty Paid). Contract arrangements which require additional transports (Delivered Duty Paid) from supplier to either storage location, or injection location are displayed in Appendices. Table 2.5 illustrates the different contract arrangements.

Transport	Contract arrangement
Supplier – Storage location	Ex Works
Supplier – Injection location	Delivered duty Paid (DDP)
Storage location – Injection location	Delivered duty Paid (DDP)

Table 2.5 Transport arrangements

2.6 Storage and Handling

There are several chains in the distribution of Production Chemicals to the final injection locations. Section 2.6 describes the storage and handling process of Production Chemicals. Before delivery of the desired chemical mix to a certain injection location, the chemicals passed several chains. The supply chain starts at the supplier, from where the raw chemicals are transported to storage locations in the Netherlands, depending on the supplier and type of raw chemical. In scope of this analysis is the moment NAM takes ownership of the Production Chemicals. We can basically distinct between three processes for distribution of Production Chemicals:

1. The supplier delivers the Production Chemicals directly to the injection location.
2. The supplier keeps raw chemicals on stock in a warehouse before it is send to the injection locations. The ability to produce oil and gas depends on the availability of Production Chemicals. Shut downs of wells occur when certain Production Chemicals are not available, so it is worthwhile to keep chemicals on stock.
3. Some Production Chemicals consists of a mixture of multiple raw chemicals. Since storage and mixing of flammable and environmentally dangerous goods require special facilities, the mixing process is outsourced to a certified organization, called JPB. Due to Dutch regulations, it is prohibited to store and mix chemicals on one site, making the process of mixing rather cumbersome. The raw chemicals are delivered to the storage location of JPB in Winschoten. When a request for special Production Chemicals are received, the raw chemicals are transported to Farmsum for mixing. The Production Chemicals are transferred back to the storage location in Winschoten before they are transported to the injection location. The cleaning of IBCs is also outsourced to JPB, which has a location in Zuidbroek where industrial cleaning takes place.
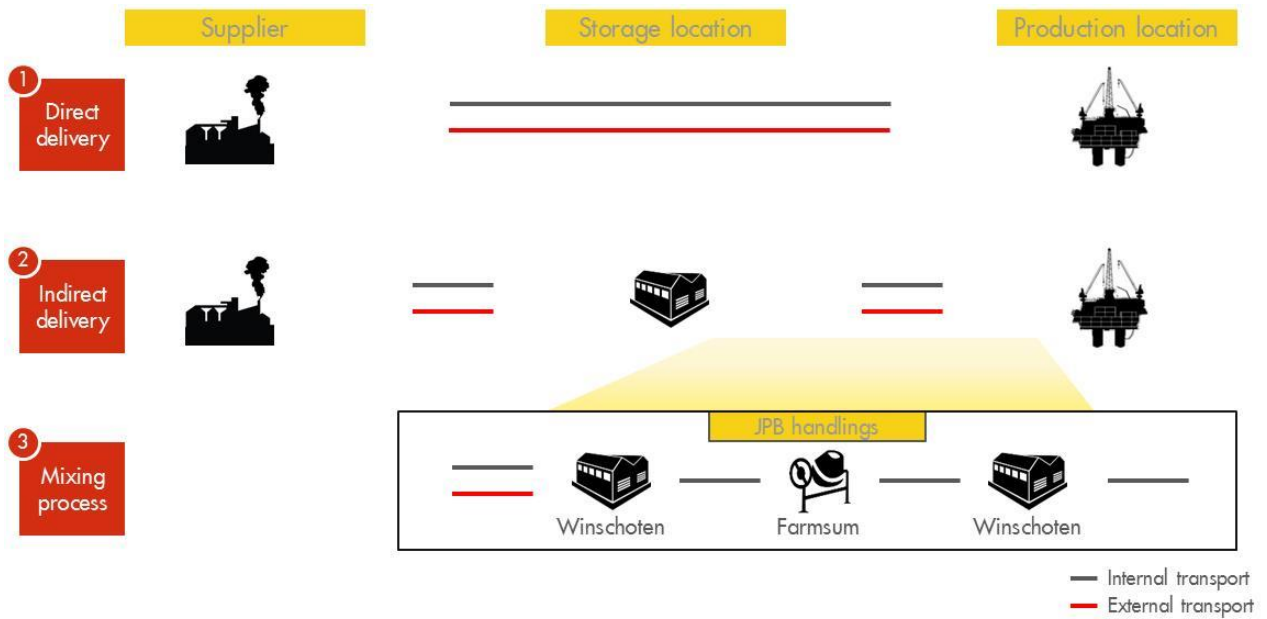
Figure 2.16 Storage and handling process

Safety is a deeply held value and Goal Zero is our vision for causing 'no harm and no leaks'. To improve safety, the NAM should strive to reduce the number of Chemical handlings within the Production Chemical process to its bare minimum. From this perspective, the NAM should strive for Direct Delivery of Production Chemicals, reducing the number of Chemical handlings.

Storage and mixing locations:

The NAM uses various locations to store and process Production Chemicals. Strategic storage spots are founded near existing oil and gas fields, as can be seen from Figure 2.17.

Figure 2.17 Storage and handling locations

We have identified five storage and mixing locations in the Netherlands with annual costs of €400K in 2014. Nearly 75% of total handling and storage costs are assigned to JPB in Winschoten/Farmsum. Most of the handlings take place at JPB, since this is the only organization which is capable to mix Production Chemicals. Tankenpark is an exceptional case, where 3 different Production Chemicals are stored and condensate is mixed with Production Chemicals. Tankenpark is property of the NAM, and costs for storage and condensate cannot be separately measured for Production Chemicals yet. Detailed information about the mixing procedures and storage locations can be found in Appendices.

Total handling and storage costs for Production Chemicals in 2014

	Storage	Handling	Transport	Total
JPB	€ 74,724	€ 189,962	€ 35,801	€ 300,487
Peterson Chemicals	€ 1,216	€ 29,901		€ 31,117
CTT Rotterdam	€ 29,785			€ 29,785
Reym Emmen	€ 42,473			€ 42,473
Total costs 2014:	€ 148,198	€ 219,863	€ 35,801	€ 403,862

Table 2.6 Storage and handling costs in 2014

3. Roles and responsibilities

Chapter 3 provides a detailed overview of the roles and responsibilities in the supply chain of Production Chemicals. Section 3.1 describes the selection of Production Chemicals. Section 3.2 provides an overview of the recurring ordering Process of Production Chemicals. Section 3.3 explains the last steps in the supply chain of Production Chemicals, the monitoring of Chemical Consumption.

The oil and gas relies on sufficient availability of Production Chemicals, as under injection results in decline of production and over injection leads to additional costs, or may even lead to gas deferments as well. Dangerous situations or incidents arise with spills of Production Chemicals. The Production Chemicals involves handlings with dangerous goods, and requires accuracy in chemical injection, which consequently requires involvement of many experts. This expertise is dispersed over four departments within the NAM.

- Contracting & Procurement
- Operations
- Production Chemistry
- Logistics

The Chemical Lifecycle consists of multiple phases. Production Chemistry already developed a Chemical Lifecycle, but this overview is specified to only the Production Chemistry department. We have critically reviewed the Chemical Lifecycle and see three different phases in the organization of Production Chemicals:

- Selection of Production Chemicals
- Recurring ordering process
- Monitoring of consumption

This research describes the Roles and Responsibilities from the moment a need for (a new) Production Chemicals has been identified. Figure 3.1 illustrates the three phases in the Chemical Lifecycle and how these phases relate to the existing Lifecycle used in Production Chemistry.
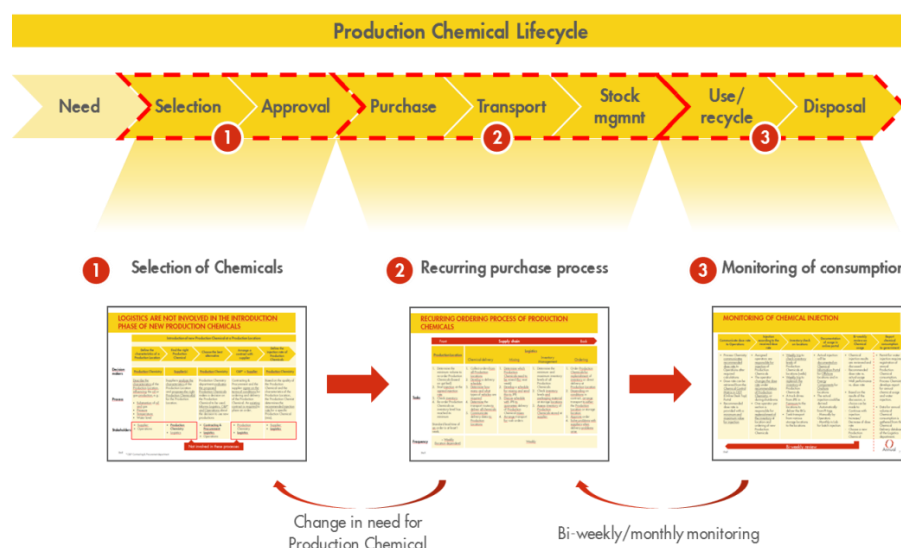
Figure 3.1 Phases in the Chemical Lifecycle

3.1   Selection of Production Chemicals

Several departments are involved in the selection phase of Production Chemicals. Selection of Production Chemicals includes all activities in:

- Introduction of a new Production Chemical in the NAM
- Using an existing Production Chemical for a new Production well
- Changing needs for an existing Production Chemical in an existing Production well

The selection of Production Chemicals consists of basically six activities. All stages in the selection of Production Chemicals are illustrated in Figure 3.2.

We can see from Figure 3.2 that Logistics is not involved in the selection of Production Chemicals. Production Chemistry proposes the new injection equipment with associated storage capacity. It might be useful to underpin the decision for storage equipment not only with expected injection volumes, but also use current replenishment frequencies to adjacent injection locations.

Another observation is that current environment in SAP only allows registration of Chemical injection permits on cluster level. Registration of a permit allows all locations within the specific cluster to order these Chemicals. Using an illegitimate Production Chemical is undesirable and government gives at least a firm penalty for exceeding the law. We do not face many problems with the Onshore permits, yet. However, for Offshore platforms, there are some location specific permits. Currently, NAM does not register the permit to SAP to prevent locations from using illegitimate Production Chemicals. The specific location has to order a 'trial' Chemical in SAP to receive the Production Chemical. Eventually, actual chemical injection volumes need to correspond with allowance on permit and should be addressed to government. Since the order name 'trial' unites, or covers, multiple Production Chemicals and orders from different locations, it is rather complex to identify the annual injection volumes for the specific Production Chemical.

Selection of Production Chemicals

Define the basis for design (BfD) for new Production Chemical	Find the right Production Chemical	Choose the best Product Chemical	Arrange permits for Chemical usage and water injection	Arrange a contract with supplier	Define the dose rate of Production Chemicals
Production Chemistry	**Supplier(s)**	**Production Chemistry**	**Operations**	**C&P* + Supplier**	**Production Chemistry**
Process Chemistry develops a basis for design of a new Production Chemical, including KPIs for the Production Chemicals. Chemical Management determines the HS&E** requirements concerning the new Production Chemicals	Suppliers analyze the basis for design and develop a new Production Chemical for the well. Supplier has to prove that the Production Chemical satisfies the requirements of the KPIs.	Process Chemistry selects the preferred Production Chemical and informs Logistics, C&P* and Operations about their decision. Chemical management approves usage of the Production Chemical, acquiring licenses and performing HS&E** checks. Chemical management develops a WIC-card/MSDS including product description, risks and risk management plan.	Operations request for a permit to use a Production Chemical for Onshore locations, together with the Legal dept.. Operations also arrange a permit for Production water injection. **Production Chemistry** Chemical management is responsible to arrange the permits for chemical usage and water injection for Offshore locations.	C&P* and supplier agree on financial terms of conditions for ordering and delivery of the Production Chemical and registers the Production Chemical in SAP **Production Chemistry + Supplier** Production Chemistry agree on the technical terms of conditions for ordering and delivery of the Production Chemical.	Based on the quality of the Production Chemical and the influencing factors, the Production Chemist determines the recommended dose rate for a specific Production Chemical (mix). Influencing factors could be: - *Gas production:* L/m3 - *Water Production:* L/m3 This is communicated to Operations.

* C&P: Contracting & Procurement department
** HS&E: Health Safety & Environment

Figure 3.2 Selection of Production Chemicals

23

3.2 Recurring ordering process

The ordering process for Production Chemicals is controlled by Operations and the Logistics department. Current ordering process from Operations is a pull process (reactive), meaning that Logistics start their activities, when requests for Production Chemicals is received from Operations.

The recurring ordering process is a weekly process and starts with an assessment of current inventory levels at injection locations by Operations, after which Operations requests for replenishment of critical inventory levels. The Planning Cell collects all requests from Operations and develops a mixing and delivery schedule to replenish the injection locations. On the other hand, Logistics manages the central inventory and requests for Production Chemicals from suppliers to replenish central inventory levels. The recurring ordering process is presented in Figure 3.3.

We have identified several observations in the recurring ordering process of Production Chemicals. Firstly, Operations define the inventory levels by checking the level meters which are installed on the storage equipment. However, during conversations with Operations, we were told that these level meters are dated and far from accurate. The level meters may deviate up to 200L from actual inventory levels at injection locations. The inaccuracy of the level meters increases risks on spills (incidents) and may result in extra costs by returning residual Chemicals. We do not have information about the evolvement of inaccuracy, but it is reasonable that inaccuracy evolves over time.

Another observation can be found in the ownership of Quality Control and Quality Assurance (QA/QC) of mixed Production Chemicals. As one can see from Figure 3.3, QA/QC of Production Chemicals, after the mixing process at JPB, is missing. The supplier of raw Production Chemicals is responsible for QA/QC of their product. However, once these raw Chemicals are combined at JPB, QA/QC of the new Chemical mix does not occur. We explicitly mentioned the combining of Production Chemicals at JPB in previous sentence, since JPB does not have the facilities to mix the Chemicals. JPB combines the Production Chemicals according to predefined mix rates, defined by Production Chemistry. It is fixed contractually that the right volumes/weights of Production Chemicals are combined at JPB. They are obliged to share the added volumes to a mix.

Stakeholders from Production Chemistry, Logistics and Operations, are all questioning the stability of the delivered Chemical mixes at Injection Locations. They even ask truck drivers sometimes to pass the roundabout twice, for additional ´mixing´ of the Chemicals. About a year ago, Production Chemistry took some samples from the Chemical mixes and the mix rates deviated significantly from recommended mix rates. Although stakeholders from different departments are questioning the stability and accuracy of the mixes, they do not see it as their responsibility to further investigate this problem, yet. Main concern for stakeholders is that under and over injection of Production Chemicals may cause gas and oil deferments, or corrodes well equipment. Suggestions for Roles & Responsibilities related to this problem and different opportunities to circumvent this problem are proposed in Chapter 10.

As we can see from Figure 3.3, the Logistics department is responsible for management of central inventories throughout the end to end supply chain of Production Chemicals. However, the roles and responsibilities for inventory management have never been defined. Logistics determines the minimum and maximum inventory levels at this moment, but there is not a standard procedure for these calculations. Logistics occasionally receives input from either Operations, or Production Chemistry for the minimum/maximum inventory levels for specific Production Chemicals. They have more insights in future demand, which makes it easier to determine the minimum and maximum levels. Regular lead times to acquire Production Chemicals are between three and six months. Pitfall to the current management of central inventories is the probability that we suddenly run out of central inventory for a specific Production Chemical, which might eventually result in a shutdown of a well. Taking this into account, average inventory levels are relatively high, to ensure delivery reliability. Either way, the current organization for inventory management is sub optimal and yields unnecessary costs. Suppliers are also required to keep 1/12th of the annual consumption on stock, to reduce the out of stock probability at central inventory. However, this is not clearly communicated in the organization and no one feels responsible for tracing this 'minimum order level'. The stakeholders are questioning whether suppliers satisfy these requirements.

Last observation relates to the chemical demand from Operations. Operations request for Production Chemicals when their current inventory level reached the minimum inventory volume (minimum order volume). Operators have to physically check these inventory levels on site. Logistics weekly collects the requests from all operators and schedules the mixing and delivery process. Currently, Logistics does not have information about the current inventory levels at locations and about the expected injection volumes for coming weeks. Without this information it is not possible for Logistics to suggest a more efficient planning for Chemical Distribution. The disability to make a general forecast for future Chemical demand results in sub optimal utilization of truck capacity and thus higher transport costs.

Front	Supply chain			Back
Operations	**Logistics**			
	Chemical delivery	Mixing	Inventory Management	Ordering
Tasks 1. Start injection at the agreed injection rate 2. Determine the minimum volume to re-order Production Chemicals (based on gut feel) 3. Check inventory 4. Re-order Production Chemicals as inventory level has reached its minimum Standard lead time of an order is at least 1 week.	1. Collect orders from all Production Locations 2. Develop a delivery schedule 3. Determine how many and what types of vehicles are required 4. Determine the transport routes to deliver all chemicals 5. Communicate delivery dates to Production wells	1. Determine which Production Chemicals need to be mixed (for next week) 2. Develop a schedule for mixing and send this to mixing locations 3. Discuss schedule with mixing locations to guarantee delivery of Production Chemical mixes 4. Arrange transport for rush orders	1. Determine the minimum and maximum inventory levels of all Production Chemicals 2. Check inventory levels and packaging material at storage locations (registered in SAP) 3. Assess inventory of Production Chemicals stored at supplier	1. Order Production Chemicals for replenishment of inventory or direct delivery at a well 2. Depending on conditions in contract, arrange transport to either the Production well or storage location 3. Solve problems with suppliers when delivery problems arise
Frequency ~ Weekly (location dependent)	Weekly			

Figure 3.3 Recurring ordering process

3.3 Monitoring of consumption

Monitoring of consumption can be divided into two stages, chemical injection and chemical consumption. Monitoring of Chemical injection occurs bi-weekly or monthly (cluster dependent) to declare inconsistencies in Chemical consumption per injection location. Inefficiencies may be caused by defects in measuring equipment, infrequent storage checks, or production shut-downs of a well. Bi-weekly review of Chemical injection is initiated by Production Chemistry in cooperation with Operations. Chemical injection permits and water injection permits require annual reporting of Chemical injection volumes per location to the government. So, the second stage of Chemical consumption monetization is to quarterly or annually define the volumes of Production Chemicals requested per well. Figure 3.4 illustrates the monetization process of Chemical consumption.

The annual report to government with Chemical consumption per well is based on Ordering data from wells in a specific year. This does not comprehend the actual injected data, since this data cannot be retrieved on well level. It is good to be aware of the fact that received volume does not one on one match the injected volumes.

We have also identified several observations in monetization of Chemical injection. First observation is about the bi-weekly/monthly review of the consumption. Injection equipment is relatively old and the injection pumps therefore have a minimum injection volume to realize stable injection. This minimum injection volume for the old fashioned pumps is relatively high, and is sometimes even higher than the recommended dose rate. As a result, over injection of Production Chemicals occur, and/or Production Chemistry dilutes the Chemicals with demi water or water condensate. In one of the conversations with the Operators, we were informed about the problems which arise when injection volumes are close to the minimum injection volumes of an injection skid. All injection points have a Low Flow Alarm (LFA), which is triggered when the injection volume drops below a specified rate (Low Flow Rate). Immediate response to the alarm is required, since the Low Shutdown Alarm (LSA) is being triggered after 24 hours, forcing a shutdown of Production. It is especially frustrating to move to injection points at unmanned installations and manually adjust their dose rates. Suggestion came from Operations to adjust the concentration of the mixes, instead of dose rates in monetization of Production Chemical injection. When the stable dose rates are above the LFA and minimum injection rates of the pumps, operators no longer face problems with the Low Flow Alarms.

The recommended dose rate is calculated by Production Chemistry. The calculation uses either the forecast for gas production, or forecasted water production. However, the actual gas and water production cannot be measured for all locations, since flow meters are not always located at each injection point. So, the recommended dose rates are based on best estimations of the gas and water production. A lot of effort is put in monitoring the actual injection volumes versus the recommended dose rates. We should be aware that the recommended dose rates are for certain injection locations based on best estimations for water and gas production.

As mentioned before, annual consumption of Production Chemicals should be reported to the government. This data is extracted from SAP, where all requests for Production Chemicals per location are stored. Requests for Production Chemicals in SAP are placed in different measuring

units. The data should be manually adjusted to uniform measuring units (e.g. Liters), before the report can be send to government, making it a time consuming exercise. We also detected a problem with Transport data. Not all visited locations can be found in the Transport data. For example, the bulk transport is only allocated to the first visited location in a trip. Following locations are not included in the data. Another problem with the data appeared during the data analysis for this research. The different datasets used for the data analysis are impossible to match. It is therefore impossible to trace the chemicals during the complete lifecycle of Production Chemicals (e.g. from acquisition to injection).

Monetization of Production Chemical consumption per location:					
Communicate dose rate to Operations	Chemical injection	Replenishment of inventory	Monthly review on Chemical consumption	Communicate adjustments to business	Report chemical consumption to government
Production Chemistry	Operations	Logistics	Production Chemistry	Production Chemistry	Production Chemistry
• Process Chemistry communicates recommended dose rate to Operations after required calculations • Dose rate can be retrieved from the Chemical Control Matrix in ODT (Online Desk Top) Portal • Recommended dose rate is provided with a minimum and maximum value for injection	• Assigned operators are responsible for injection of Production Chemicals • Adjust dose rate under recommendation of Production Chemistry, or during shutdowns • Adjust minimum and maximum inventory level when dose rate changes • Reorder Production Chemicals	• Adjust minimum and maximum inventory levels according to dose rates • Reorder when inventory level is below minimum	• Actual injection documented in Energy Components • Analysis of injection per Production System are derived from Business Objects • Chemical injection results are reviewed and discussed: - Recommended dose rate vs. actual usage - Well performance vs. dose rate	• Based on the results of the discussion, a choice can be made to: - Continue with injection - Increase/ Decrease of dose rate - Choose a new Production Chemical • Process Chemistry informs Operations and Logistics when adjustments in Chemical injection volume are preferred	• Process Chemistry registers annual chemical usage and water injection per location for government • Offshore: Quarterly monetization of Chemical consumption to check whether actual chemical injection is in line with permit • Data for annual volume of Chemical consumption is gathered from the database in SAP.

Bi-weekly/monthly review

Annual

Figure 3.4 Monitoring of Production Chemicals

29

3.4 RACI matrix

After meetings with many stakeholders from different departments, we conclude that a general overview of the Chemical Lifecycle is missing. Section 3.4 provides an overview of the roles and responsibilities in the Lifecycle of Production Chemicals.

This overview is displayed in a RACI-matrix and includes roles and responsibilities of all departments involved in the Chemical Lifecycle. The matrix has been verified with the business unit leads and can be applied to the Corporate Management System. Benefits of widely using this RACI-matrix for the NAM are (Six Sigma Tutorial, 2011):

- Reduces misunderstandings
- Assigns accountabilities to each role
- Eliminates duplications of effort
- Improves understanding of cross-functional view of employees across divisions or departments

Overall, this RACI matrix prevents waste activities throughout the supply chain, which relates to the overall objective to deploy logistical resources effectively.

The matrix describes all steps in the supply chain of Production Chemicals, who is responsible for execution of the steps and which departments should be involved in these steps. The RACI matrix is presented in Figure 3.5. The hard copy version of this research displays the matrix in A3 format to make the RACI matrix easier to read.

As mentioned in Section 3.2, roles and responsibilities for central inventory management and QA/QC of mixed Production Chemicals are not defined. The RACI matrix does not involve these responsibilities, but we touch upon the recommendations regarding these issues in Chapter 10.

Production Chemical Lifecycle - RACI Matrix

Phase	Action	Production Chemistry			C & P	Operations	Logistics	JPB	Vendor	Legal department
		PCT	CMT	Contract holder		Plant representative	Planning Cell	Mixing location	(In) Direct delivery	Legal
Production Chemical selection — *No frequency*	Develop terms of references and KPIs for new Production Chemical	EXE							INF	
	Propose a suitable Production Chemical	INF							EXE	
	Select Chemical or Replacement Chemical	EXE	INF						INF	
	Technically approve chemical	EXE	INF						INF	
	Chemical Approval Request: Perform Preliminary RAM screening	CON	EXE							
	Chemical approval (legislation)	CON	EXE		INF					
	Calculate and communicate mix rate for injection	EXE				INF	INF	INF	CON	
	Calculate and communicate dose rate for injection	EXE				INF			CON	
	Purchase injection and storage equipment required for injection at Production Location	CON				EXE				INF
	Request for Permit from government to use Production Chemicals on Onshore locations	CON	INF		INF	CON				EXE
	Request for Permit from government to use Production Chemicals on Offshore locations	CON	EXE		INF	INF				INF
	Publish amended location specific Approved Chemicals lists (incl. MSDSs and WICs)	INF	EXE		INF					
	Amend contract with vendor	INF		CON	EXE				CON	
	Register Production Chemical to Material Master in SAP	INF			EXE					
	Inform chemical readiness to business	EXE	INF	INF	INF	INF	INF		INF	
Recurring ordering process — *Weekly*	Start injection of Production Chemicals within a range of the recommended dose rate	CON				INF	EXE			
	Determine minimum and maximum inventory levels for central inventory	CON				INF	CON	EXE	INF	
	Register minimum and maximum inventory levels for central inventory in SAP				EXE		INF			
	Determine minimum and maximum inventory levels for inventory at injection locations					EXE	INF			
	Check inventory at central storage locations in SAP				CON		EXE		INF	
	Inventory control at vendor for requested products			CON			INF		EXE	
	Request for Chemicals to be used as central inventory			CON	CON	CON	EXE		INF	
	Check inventory at Production Location	INF				EXE				
	Request for Production Chemicals from Production Location					EXE	INF			
	Collect requests and schedule the mixing process						EXE	INF		
	Mixing process of Production Chemicals at JPB	INF					INF	EXE		
	Measure quantities of different Production Chemicals in Chemical mixtures	INF		INF			INF	EXE		
	Schedule transport for Production Chemical delivery						EXE		INF	
Audit on stock levels — *Annually*	Annual audit on physical inventory vs. administrated inventory at central storage locations				EXE		CON			
Monitoring of chemical injection — *Monthly*	Analyze/Monitor Production Chemical consumption vs. recommended dose rate	EXE				INF				
	Review recommended dose rate at a location	EXE				INF			CON	
	Adjust dose rate at a location	CON				EXE			INF	
Monitoring of chemical consumption — *Quarterly/Annually*	Extract annual Chemical consumption data from SAP	INF	INF				EXE			
	Quarterly monetization of (Offshore) Production Chemical consumption vs. allowance on permit	INF	EXE			INF				
	Develop annual Chemical consumption reports	INF	EXE				CON			INF
	Send annual Chemical consumption report Offshore to government		EXE							INF
	Send annual Chemical consumption report Onshore to government	INF	INF							EXE

EXE	Executed: responsible to do it or get it done
CON	Consulted: on tasks and results; only as necessary
INF	Informed: about tasks and results

Figure 3.5 RACI-matrix

4. Improvement areas

Chapter 3 generated an overview of the Roles & Responsibilities of the Chemical Lifecycle and delivered a RACI matrix to streamline the activities in the organization of Production Chemicals. During meetings with the stakeholders, we also observed other issues regarding the process. Chapter 0 summarizes the nine observations described in Chapter 3. Figure 4.1 addresses the key issues, the (potential) impact, and the concerning departments. We have circled the issue regarding ownership in QA/QC of mixed Production Chemicals, since the responsibilities regarding QA/QC have never been defined yet.

Department	Observations	Impact
Contracting & Procurement	**1** <u>Data inconsistency:</u> Requests for Production Chemicals in SAP in different measuring units, and Production Chemical data from different databases are hard to match	Difficult and time consuming to analyse and link data, required for annual report to government for water injection permit
	2 <u>SAP registration of permits is on cluster level.</u> Permission for only one location within a cluster is not possible yet (ONEgas)	Permission for only one location within a cluster is not possible yet. Current problem for ONEgas East
Operations	**3** <u>Minimum injection flow for Production Chemicals rather high</u> due to dated injection equipment	Over injection and/or increase in numbers of different diluted Chemical mixes
	4 <u>Equipment</u> to measure the inventory at injection locations is <u>dated and not always accurate</u>	Risks for safety incidents and extra costs for handling of residual Chemicals
Production Chemistry	**5** <u>Actual gas and water production</u> cannot be measured for all locations since flow meters are not always available per location	Monetization of Production Chemical consumption based on best estimation of gas and water production
	6 Propose sufficient storage equipment at a Injection Location but Logistics is not involved	Waste in transport costs due to inefficiënt storage equipment at Injection Locations
	7 <u>Limited (ownership of) QA/QC</u> of mixed Production Chemicals delivered to Injection Locations	Unreliable and unstable quality of mixed Production Chemicals at locations
Logistics	**8** <u>Roles & Responsibilities</u> and <u>procedures</u> for <u>central inventory management</u> are not recorded	Sub optimal inventory control at central storage locations
	9 <u>Limited coordination</u> of Chemical <u>consumption and requests</u> from different Injection Locations does not allow for horizon planning	Sub optimal utilization of truck capacity resulting in high transport costs

Figure 4.1 Issues in the organization of Production Chemicals

4.1 Research focus

From here, we focus on improving the current organization. We could not resolve the concerns for all addressed issues, considering the limited duration of six months for this graduation project. We are therefore forced to prioritize the issues and to conduct an optimization study for only one issue.

In the light of my graduation research, we focus on the issue where my technical study background could add most value to the business. We also consider the urgency of the issues and the likelihood of implementing the solutions. We defined three potential optimization studies regarding issues 6, 8 and 9. The objective and characteristics of these optimization studies are illustrated in Figure 4.2 below:

6	**8**	**9**
Reduce transport costs by changing injection facilities	**Optimize inventory management at central storage lcoations**	**Increase capacity utilization in transport of Production Chemicals**
Annual costs: €700,000.-	*Annual costs: €70,000.-*	*Annual costs: €700,000.-*
▪ High investment costs from Operations to change storage equipment or packaging materials	▪ Requires a consumption forecast of multiple months ▪ Relatively low financial benefits ▪ Applicable to only one storage location (JPB) ▪ Increase in reliability of delivery	▪ Requires a consumption forecast of a few weeks ▪ Supports both Logistics and Operations in daily work ▪ Significant financial benefits Reduces number of physical checks at injection locations

Figure 4.2 Potential optimization studies

We have discussed the potential optimization studies with the project stakeholders. The conclusion of our discussion is to focus the remainder of this graduation project on increasing capacity utilization in transport of Production Chemicals (issue 9). The objective for this optimization study is to minimize total duration of the replenishment cycle of supplying Chemical Injection locations. Besides cost reduction, the study provides more control over the replenishment process. This enables Logistics to shift from a reactive scheduling process to proactive planning of replenishments. We initially focus on the replenishment of IBCs, since this yields highest potential benefits.

As described in Section 2.5, the IBCs are delivered with flat transport and the IBC trip occurs at least once a week to visit a predetermined set of injection locations. We distinct two replenishment cycles for IBCs, namely the locations in Western part of the Netherlands and the Northern part of the Netherlands. Our research concerns only the Northern part of the Netherlands. This replenishment cycle consists of many injection locations and combines orders from multiple operators. Once we have conducted the optimization study for the North, it would be relatively simple to reproduce this model for the Western part of the Netherlands. Further details about the replenishment cycle of IBCs are explained in Section 4.2.

We also stressed the importance of optimizing central inventory management (issue 8). However, the optimization study would emphasize on defining procedures and Roles & Responsibilities rather than building analytical models. This study would therefore not comply to Graduation requirements from University. We refer to the optimization of inventory management at central storage locations in Chapter 8.

Reducing waste in replenishment costs by changing injection facilities, involves high investment costs for Operations (issue 6). The optimization study for this issue requires full control over the current replenishment cycle to assess the potential benefits of changing the injection capacity or mode of transport. Therefore, we place this optimization study (temporarily) on a hold.

4.2   Increase capacity utilization in transport of Production Chemicals

Section 4.2 explains the current replenishment process of IBCs and its characteristics for area North. Four operators are in charge for the replenishment of Production Chemicals. Currently, the Planning Cell (within Logistics) collects all orders from these operators, once a week. These orders are handled and transport for distribution is scheduled on Wednesday, the week after the orders were placed. The Production Chemicals are stored at JPB in Winschoten, from where all IBCs are delivered to the locations. We currently have a total of 61 injection locations in the North.

The operators have their own procedure for deciding when to request for new Production Chemicals. The storage capacity of injection equipment varies between 1,000L and 10,000L. As already identified in Chapter 0, the accuracy of level meters at storage equipment is questionable. Operations therefore uses a maximum inventory level which is generally lower than capacity. The injection pumps require a minimum volume to be able to inject Chemicals. We define the (maximum) expected injection between two subsequent Chemical distributions. The expected injection until the next distribution and the minimum injection volume add up to the minimum order level of an injection location. Figure 4.3 demonstrates the different levels at a storage location.
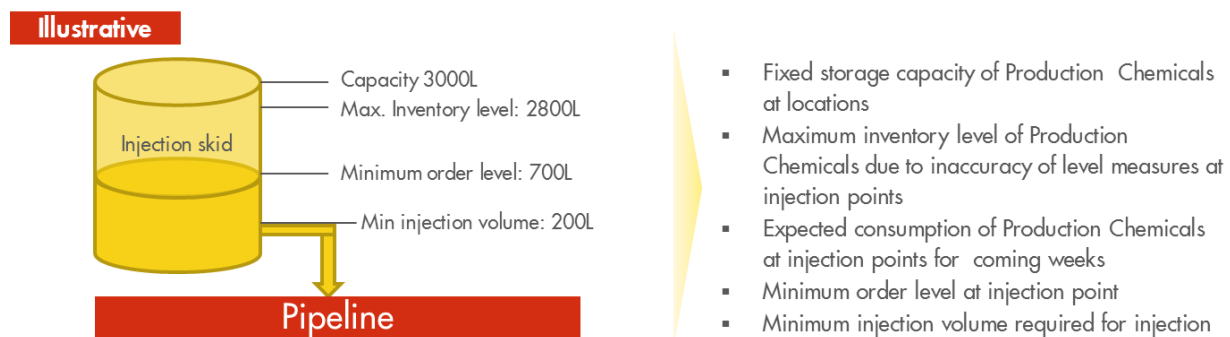
Figure 4.3 Inventory levels at injection locations

The operators request for new Production Chemicals when the inventory level reaches the minimum order level. The operator generally request for the maximum amount of Production Chemicals without interfering with storage capacity at the injection location.

Based on the individual orders from operators, the Planning Cell arranges transport to the different Injection Systems. The Planning Cell aims to schedule one IBC trip a week to replenish all the Injection Systems in asset North, Groningen and East. However, we identified limited coordination of these requests. Therefore, it may occur that multiple IBC trips in are scheduled in one week. The organization for the weekly IBC trip is shown in Figure 4.4.

- There is a weekly trip on Wednesday to replenish injection points
- The truck is loaded on Tuesday, which takes around 4 hours
- Duration of chemical unloading at injection point is 15 minutes
- Known duration to travel between injection locations
- Requests in multiples of 1000 Liters, since Production Chemicals are delivered in IBCs of 1000 Liters
- Capacity of a truck is 22 IBCs
- 61 injection locations

Figure 4.4 Weekly IBC replenishment trip

In order to increase capacity utilization of trucks, we must improve coordination of the Chemical consumption and requests. We improve coordination by developing a Model which automatically calculate current inventory levels and forecast Chemical injection. We have seen in Section 3.3 that the actual Chemical injection is recorded in a system called Business Objects. Once we have an overview of all inventory levels on a specific date, we could calculate the "real time" inventory levels from there. Based on historic consumption, we could also determine expected injection volumes. This information is the basis for successful coordination of the Chemical requests. This information, together with some location specific details allows for proactively proposing a planning for the weekly IBC trip, which will be presented in Chapter 6. Figure 4.5 addresses the final deliverable and potential advantages of the Chemical Distribution Model.
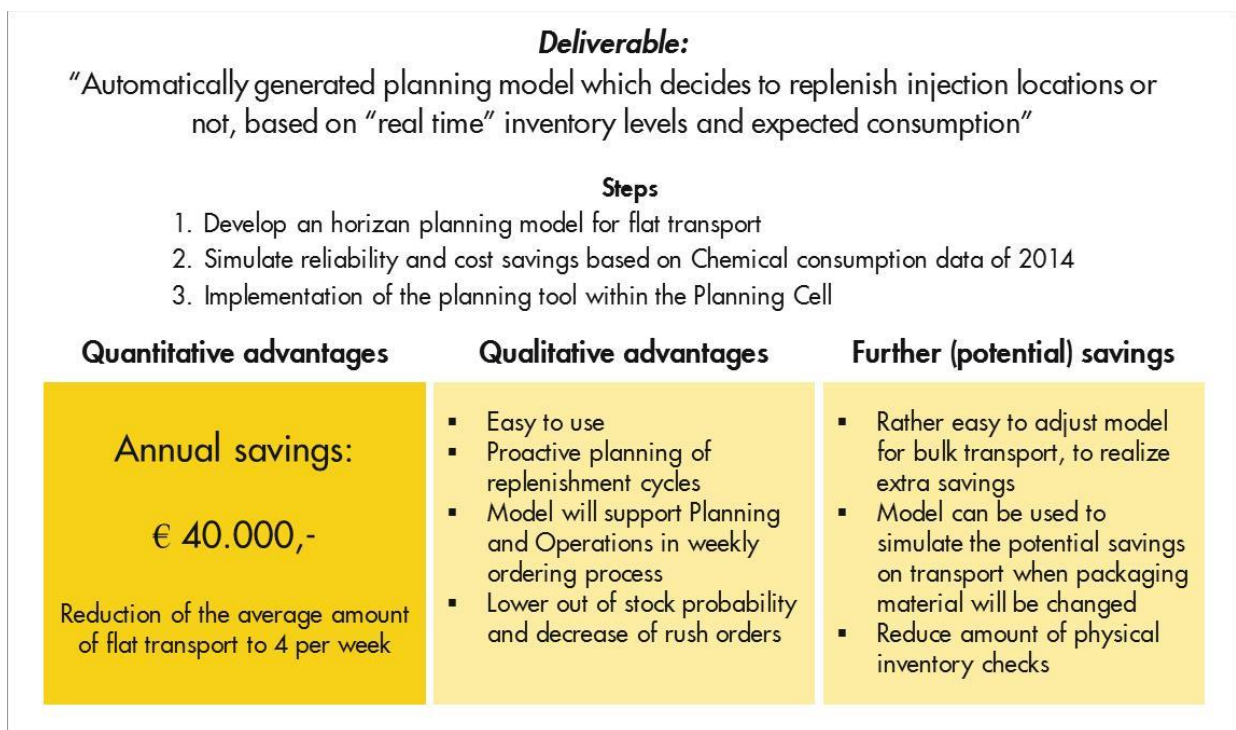
Figure 4.5 Chemical Distribution Model

5. Literature Review

Chapter 5 provides an overview of the existing literature regarding Vehicle Routing Problems (VRP) and Rolling Horizon Planning (RHP). First, we elaborate on the Rolling Horizon Planning models in Section 5.1. We describe the existing models about Vehicle Routing Problems and their implications in Section 5.2.

5.1   Horizon Planning

Horizon Planning was first introduced in the paper of (Modigliani & Hohn, 1955). This schedule was meant for the Production industry to produce product x_j in j-th period. This model aims to minimize total production costs, given the amounts required in each of T future periods of time. So, the problem of scheduling the production of a product x over T equal, successive periods is considered as:

1. Meet initially known requirements s_1, s_2,..., s_T
2. Incurring the lowest possible costs

As already mentioned, we consider x_j as the production of product x in the j-th period. $\sum_{t=1}^{k} x_t$ is the cumulated consumption and $S_k \sum_{t=1}^{k} s_t$ is the cumulated consumption until period k. Let h_0 denote the beginning inventory and h_k denotes the inventory at the end of period j. The inventory at the end of period j can be derived from following equation:

$$h_k = h_0 + X_k - S_k$$

Where h_k should be at least 0 for all k (k = 1, 2, 3, ..., T).

A lot of research has been conducted after the introduction of horizon scheduling of (Modigliani & Hohn, 1955). (Suresh, Ning Hsu, & Suresh, 2002) developed a classified bibliography of the horizon scheduling literature. They have identified three different horizon types.

The horizon type:

The literature distinguishes three types of horizons. Let an integer Z ≥ 1, be the length of the terminal length or the problem horizon. The problem can be either finite, when Z ≤ ∞, or infinite otherwise. Problems are called *Forecast horizons* and *Solution horizons* when the optimal decision in periods (1, T) are unaffected by the model parameters in periods (T + 1, Z). *Solution horizons* require, in contradiction to the *Forecast horizon,* a complete knowledge of all model parameters (T + 1, Z). In dynamic environments, one may decide to use *Rolling horizons* in planning decision making. In *Rolling horizons,* an R_1-period is defined based on an sufficient forecast period. A schedule is developed for all the individual periods within length R_1, but only the decision for the first period is being implemented. At the beginning of the next period, a new schedule is developed for period R_2, where the end date of period R_2 may differ from R_1. The forecasting period R_x is restricted to a finite horizon. The number of periods within the *Rolling horizon* is called the *Study horizon.* The term *horizon* refers to the number of periods in the future for which a forecast is made (Sethi & Sorger, 1991). The effectiveness of rolling horizon scheduling was first assessed by an experimental study of

Baker (Baker, 1977). This study revealed that rolling horizon schedules achieves costs within ten percent of optimality. As benchmark for the optimal solution, Baker used the solution for the complete forecast horizon (48 periods) of the Dynamic Lot Sizing Model (Wagner & Whitin, 1958). Optimality of the *Rolling horizon* schedule is negatively affected when the forecast of the periods within the forecast horizon needs to be amended, or when the *Study horizon* is smaller than the forecast horizon. The *Rolling horizon* is most optimal when the *Study horizon* approaches the forecast horizon (Suresh, Ning Hsu, & Suresh, 2002). Figure 5.1 demonstrates a planning for both the *Forecast* and *Rolling Horizons.*

Forecast Horizon for Production						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Week 1	500	350	350	0	600	0

Forecast Horizon

Rolling Horizon for Production						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Week 1	500	350	350	0		
Week 2		350	350	0	600	
Week 3			400	0	600	0

Rolling Horizon

Figure 5.1 Forecast and Rolling horizon planning

Conclusion

Forecast horizons and *Solution horizons* are not applicable to our model as the optimal decision in periods (1, T) are affected by their successor periods. With *Rolling horizon* planning on the other hand, we have the ability include the successor periods in the planning. We are unfortunately not able to make a fully accurate forecast of Production Chemical consumption for a forecast horizon. Even for a period of one week, we face uncertainty in consumption forecast. This negatively impacts the optimality of the solution.

5.2   Vehicle Routing Problem

The predecessor of the Vehicle Routing Problem (VRP) was introduced in a paper of (Dantzig & Ramser, The Truck Dispatching Problem, 1959), right after the introduction of Horizon Planning. They used the term Truck Dispatching Problem for what we currently describe as the Vehicle Routing Problem in literature. The Vehicle Routing Problem is an extension to the Traveling Salesman Problem (TSP). The core problem for a TSP is the following: Find the shortest route (tour) for a salesman starting from a given city, visiting each of a specified group of cities, and then returning to the original point of departure (Dantzig, Fulkerson, & Johnson, Solution of a large scale traveling salesman problem, 1954). In addition to the TSP, the VRP does not restrict the algorithm to develop exactly one tour to visit each location. So, the VRP allows multiple vehicles to conduct a complete tour. Figure 5.2 graphically illustrates the difference between TSP and VRP.

Traveling Salesman Problem   Vehicle Routing Problem
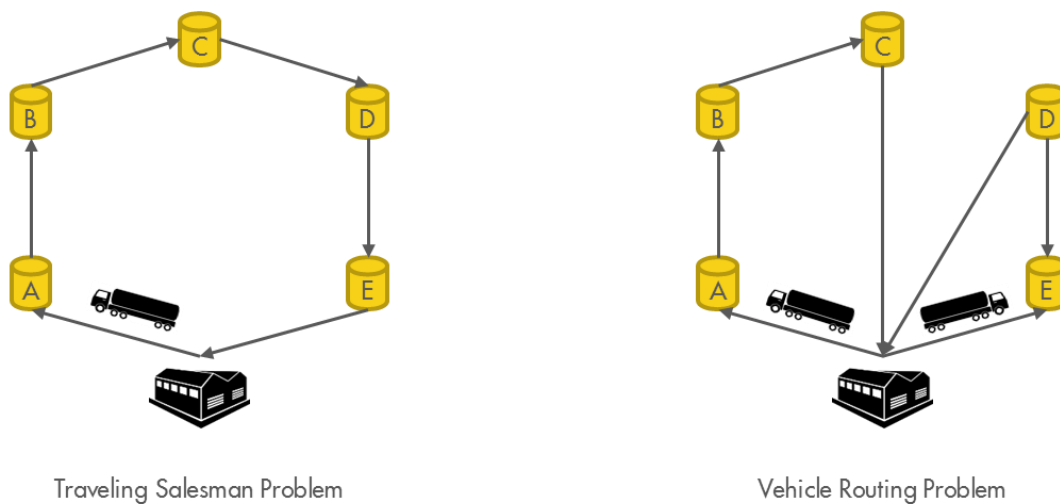
Figure 5.2 Traveling Salesman and Vehicle Routing Problem

There is a wide variety of literature available on VRP, and there is a common understanding of the VRP (Cordeau, Gendreau, Laporte, J-Y, & Semet, 2002) (Laporte, The Vehicle Routing Problem: An overview of exact and approximate algorithms, 1992). Let graph $G = (V, A)$, where $V = \{0,1,\ldots,n\}$ is a set of vertices, representing the customers and the depot positioned at vertex 0. A is a set of arcs between cities (i,j) $i \neq j$. Each arc is associated with a travel distance C (c_{ij}). The travel costs may depend on travel distance, duration, or any other costs related to an arc. Each customer $i \in V \setminus \{0\}$ has a non-negative demand q_i and a service time t_i. The classical VRP assumes that a fleet of m vehicles are located at the depot with equal capacity Q. The number of vehicles used m is known in advance, or can be used as decision variable. The VRP designs a set of vehicle routes such that:

(i)   Each route starts and end at depot
(ii)   Each customer $i \in V \setminus \{0\}$ is visited exactly once by exactly one vehicle
(iii)   Total demand of one route does not exceed vehicle capacity Q
(iv)   The total duration of one trip does not exceed give limit D
(v)   Total routing costs is minimized

The VRP still is a popular topic for literature studies and there still is a rising trend in the number of articles published in the field. Over 1000 articles related to VRP have been published until 2006. The most frequently appearing researchers are Gilbert, Laporte, Gendreau, Potvin, Golden, Solomon, and Tarantilis (Eksioglu, Vural, & Reisman, 2009).

Diverse extensions and variants to the classical VRP have been introduced over time. Section 5.2.1 elaborates on the different variants of the VRP, after which the various methods to solve VRPs are explained in Section 5.2.2.

5.2.1   Variants to the classical Vehicle Routing Problem

We have seen from Section above that a lot of research has been conducted to extend the classical VRP to various real life situations. The classical VRP already considers capacity constraints for the available vehicles. The classical VRP may also appear in literature as capacitated VRP (CVRP). Section 5.2.1 describes the characteristics for some of the other variants of the VRP.

Dynamic VRP (DVRP): The classical VRPs focus on the static cases, where information is known at the time of planning of the routes (Larsen, 2000). In contradiction to the Static VRP, input may change (or be updated) while solving the algorithm or executing the trip in the Dynamic VRP (DVRP). DVRP differs from the static VRP in many ways, but the main difference applicable to our project is that in DVRP (Psaraftis, 1988):

    (i)   Future information may be imprecise or unknown
    (ii)   Flexibility to vary vehicle fleet size is lower

Stochastic VRP (SVRP): VRPs are called stochastic whenever some elements of the problem are random. Customer demand or travel times are often the stochastic elements. Most classes of SVRP cannot be solved to an exact solution, so it is rather difficult to assess the quality of the SVRPs (Gendreau, Laporte, & Séguin, 1996).

Time windows (VRPTW): The VRPTW considers allowable distribution times, or better known as time window constraints, as extension to the classical VRP. This basically means that the costs of waiting time are also incurred in minimizing the total scheduling and routing costs. Early arrivals at the customer or loading/unloading locations may result in additional waiting time and costs. Assume customer i request for a service with a service time s_i, and the service can begin at time b_i. Let e_i be the earliest time the service may start at customer i and l_i be the latest time a customer l permits a service to start. When the vehicle arrives earlier than the earliest start time of a service e_i, the vehicle must wait until time e_i with associated costs (Solomon, 1987).

Multi-depot VRP (MDVRP): A frequently used generalization of the classical VRP is the Multi-depot VRP. In the MDVRP, each customer is visited exactly once by one truck departing from one of multiple depots. The restriction that every vehicle must start and end at the same depot is still valid in this case. Similar to most generalizations of the classical VRP, exact algorithms for this problem only work well for relatively small problems (Crevier, Cordeau, & Laporte, 2005).

VRP with Pick-up and delivery (VRPPD): In the VRPPD, a set of heterogeneous vehicles, based at one or multiple locations, must satisfy a set of requests. A request consists of a pickup location, a delivery location and a demand to be delivered at the delivery location. Constraints which are added to the classical CVRP are (Desaulniers, Desrosiers, & Soumis, 2002):

(i)   Visit each pickup and delivery stop exactly once
(ii)   Coupling the pickup and corresponding delivery stops on the same vehicle routes
(iii)   Impose visit precedence among each pickup stop and its associated drop-off stop
(iv)   Ensure vehicle returns to the appropriate base location after completion of the tour

Tucker-Miller-Zemlin constraint: To assure that subtours are eliminated from the classical VRP, the VRP should insert extra constraints. Miller, Tucker and Zemlin invented a way to prevent a TSP algorithm from making subtours in the early 60's (Miller, Tucker, & RA, 1960). Over the past decades, this model has been amended in such a way that research has proofed the that the so called Tucker-Miller-Zemlin constraints are valid inequalities for the CVRP (Kara, Laporte, & Bektas, 2004). The model basically assign the orders of each customer to a place at the vehicle. This constraint adds two variables u_i and u_j which represents the demand of visited customer i and succeeding customer j at the vehicle. The demand x_i of the first visited customer is assigned to the first x_i places of vehicle with capacity C. Demand of the succeeding customer is assigned to the places x_{ij}, which should be larger than x_i, but not more than the vehicle capacity. This constraint assures that all subtours are eliminated.

5.2.2   Solving VRPs

Section 5.2.2 focuses on the different methods to solve VRPs. There are basically two different approaches to solve a VRP, *exact algorithms* and *heuristics.* The VRP is NP-hard, since it includes the TSP, where *m = 1* and *Q = ∞.* However, the VRP is considerably more difficult to solve than the traditional TSP of the same size. The most sophisticated exact algorithms are able to solve instances of up to 100 vertices. Opposed to the VRPs, the TSPs can solve exact algorithms of hundreds, or even thousands of vertices, using the branch-and-cut-and-price algorithms (Laporte, What You Should Know about the Vehicle Routing Problem, 2007).

Exact algorithms

Since exact algorithms are limited to solve VRPs to optimality up to about 100 customers, literature has been focusing more on the heuristics. However, we have also seen that TSP problems can be solved involving thousands of vertices. This section describes *branch-and-bound* and *branch-and-cut* methods, which are frequently used in literature over the last decades (Cordeau, Laporte, Savelsbergh, & Vigo, 2007).

Branch-and-Bound: The branch-and-bound method is introduced to intelligently enumerate all feasible points of a combinatorial optimization problem. The VRPs are NP-hard problems, making it hopeless to look to all feasible solutions. The branch-and-bound method constructs a proof that a solution is optimal, based on successive partitioning of the solution space (Papadimitriou & Steiglitz, 1998). First iteration is to partition a set of all feasible solutions into subsets. Each subset is

represented by a child of the original node. During the branching process, the algorithm eliminates all subsets which does not result in the optimal solution, based on values of the upper and lower bound of the objective value. We explain this process with a minimization example:

A lower bound is assigned to each subset of solutions created during the partitioning process. The value of the lower bound. The value of all feasible solutions of the subsets is at least the value of the lower bound. The upper bound is the value of the best solution so far. Numerous iterations take place until the algorithm found a value for the upper bound, equal to the lower bound of all solutions, or when there is only one subset of possible solutions left (Tijms, 2004). For larger problems, the problem cannot be solved to optimality in polynomial time. For this reason, many branch-and-bound procedures enables users to stop the algorithm to check whether the method found values for the lower and upper bound within the predetermined acceptable range (Tijms, 2004).

Branch-and-Cut: The branch-and-cut algorithms are the best available exact approaches for solving VRPs (Cordeau, Laporte, Savelsbergh, & Vigo, 2007). The branch-and-cut algorithm is a combination of cutting plane method with the general branch-and-bound algorithm. The branch-and-cut problem first solves the LP-relaxation to find a lower or upper bound (depends on the objective function). The branch-and-cut algorithm may decide to add a cutting plane to the LP relaxation. The cutting plane approach adds valid inequalities to the problem to ultimately find a solution with integer variables (Mitchell, 2002).

Heuristics

Since exact algorithms for VRP are only adequate for smaller sized problems, heuristics have been introduced as alternative. The classical heuristics have been developed to quickly obtain a feasible solution and possibly apply a post optimization procedure to the feasible solution. The heuristics do not yield an optimal solution for the VRP, but a solution which slightly deviates from optimum. Several classical heuristics have been developed, whereas the literature primarily refer three algorithms (Cordeau, Laporte, Savelsbergh, & Vigo, 2007):

(i)   Clarke and Wright savings algorithm
(ii)   Gillet and Miller sweep algorithm
(iii)   Fisher and Jaikumar algorithm

Clark and Wright savings: Conform all heuristics, the Clark and Wright savings algorithm starts with a feasible solution, consisting of multiple routes. The concept of the savings algorithm is to obtain costs savings by merging two routes into one route (Clarke & Wright, 1964). In the first step of the algorithm, the savings for all pairs of customers are calculated and sorted in descending order of savings. When a combination of i and j is considered, the two routes visiting i and j are combined, if this still yields a feasible solution. So, merging these points can be done without deleting a previously established direct connection, and total demand does not exceed vehicle capacity. Two variants of the Clark and Wright savings algorithm could be applied. The *sequential algorithm* builds on exactly one

route at a time and the algorithm stops when no extra feasible combinations exist. The *parallel algorithm* may build on multiple routes at the same time and merges the routes with highest cost savings (Lysgaard, 1997).

Gillet and Miller sweep: The Gillet and Miller sweep algorithm is another well-known heuristic to solve the VRP. They graphically display the locations of the depot and all customers on a map. Feasible routes are created by simply rotating a ray centered at the depot and include all customers in the vehicle route. The route returns to depot when the vehicle capacity exceeds its maximum or maximal route length is attained. A new route is initiated and follows the same procedure (Cordeau, Laporte, Savelsbergh, & Vigo, 2007).

Fisher and Jaikumar: The heuristic of Fisher and Jaikumar is also known as the cluster first, route second approach. The algorithms consists of two phases, in which all customers are first assigned to one cluster, solving a Generalized Assignment Problem (GAP). Next, the delivery sequence per cluster is determined by applying a TSP heuristic or algorithm (Fisher & Jaikumar, 1981). The GAP is NP-hard and can be solved using relaxation techniques, for example the Langrangian technique. There still are some misgivings about the performance of this heuristic, since the solutions of Fisher and Jaikumar cannot be verified. However, computational experiments suggest that the Fisher and Jaikumar is not simple to program (Cordeau, Laporte, Savelsbergh, & Vigo, 2007).

Conclusion

Starting from the 50's of previous century, a lot of research has been conducted regarding VRP. Result is that we currently have over 1000 articles with variants to the VRP. The VRP is a generalization of the TSP. The TSP considers only one route, with the start and end at the depot. In between, all customers are being visited. The VRP deteriorates from the TSP, by considering multiple routes with capacitated vehicles.

Since VRPs are NP-hard problems, a lot of research has been conducted regarding solving algorithms for the VRP. Exact algorithms for the VRP can only solve the problem within polynomial time for smaller problems. However, research has also shown that TSP problems can be solved with exact algorithms for thousands of vertices. As exact algorithms are not appropriate to solve VRPs in most cases, heuristics are being used. Heuristics solve the VRPs to a fraction of optimality within polynomial time.

We have described the current situation of ordering Production Chemicals within NAM. This problem seems to be a capacitated VRP, since at least one truck a week is being used to supply Production Locations with Production Chemicals. However, treating the problem as a VRP makes us dependent on heuristics for solving the VRP. In order to make a successful planning Model, which can be widely introduced within the NAM, we have to consider user-friendliness of the Model and the software should be available for the Planning Cell. Taking these constraints into account, Excel is the only software which can be used to develop a user-friendly Model. By simply adding the constraint that we

may only use one truck to deliver the Production Chemicals, we can change the problem to a TSP with capacity constraint. We limit scope for the replenishment of Production Chemicals to the Northern part of the Netherlands. Decent planning does not force us to use more than one truck a week. The Western part of the Netherlands is out of scope, and weekly distribution of these Production Chemicals is conducted by a different truck.

Our TSP problem is developed in Excel and solved with an exact algorithm. We have seen in literature that the branch-and-cut method is the most efficient Model, so we use this algorithm in solving our weekly TSP problem.

The model is slightly different from what we have seen in literature so far. The Model which is developed generates a solution for a capacitated TSP problem, where the customer may, or may not be visited.

6. Hybrid horizon traveling salesman scheduling

Chapter 6 describes two different types of planning heuristics. In this Chapter, we combine the horizon planning method and the capacitated traveling salesman problem to develop a Chemical Distribution Model. We proposed the name '*Hybrid horizon traveling salesman scheduling*' for the mathematical calculations in the model. The trucks used to replenish the injection locations is operated by another organization. Total costs for the weekly IBC trip solely depend on the total duration of the trip. This model minimizes the total duration of Production Chemical's replenishment with a planning horizon of four weeks. However, only the planning for the first week is being implemented. Total duration of the weekly IBC trip consists of:

- Loading the truck at central storage location
- Unloading truck at injection points
- Travel time between injection points to be replenished

Scope:

As described in Section 4.2, we start with a planning model for the weekly IBC trip in the Northern part of the Netherlands, which are sub divided in area North, Sour Gas, and East. These areas facilitate 62 injection points in Friesland, Groningen and Drenthe. Furthermore, Chemical distribution with Bulk and Vessel transport is out of scope.

Assumptions of the model:

- One truck is able to deliver all Injection Systems
- Given truck capacity of 22 IBCs
- Chemicals are delivered in IBCs
- No restriction on maximum duration of a trip
- Truck drivers are legally obliged to take a break
- Weekly IBC trip starts on Wednesday and may continue on Thursday if necessary
- All IBCs are loaded at storage location JPB in Farmsum
- Start and end location is JPB in Farmsum
- Fixed unloading time of IBCs at Injection System

The formulation of Chemical Distribution Planning problem can be described as follows:

Sets:

Number of trucks used to deliver the IBCs to the Production Locations K = {0,1}
Set of potential locations to depart from I = {0,1,2,3,...,61}
Set of weeks in which locations can be delivered T = {0,1,2,3,4}

Indices:

k ∈ K
i,j ∈ I
τ ∈ T

Parameters

Maximum orders to be placed $m_{i\tau}$ for location i in week τ
Capacity c_i of storage at location i
Expected inventory level of Production Chemicals $e_{i\tau}$ at location i in week τ
Expected injection volume of Production Chemicals $v_{i\tau}$ location i in week τ
Minimum order level for Production Chemicals s_i on location i
Duration d_{ij} to drive from location i to location j
Duration b to load Production Chemicals at central storage location
Duration r for the legally obliged breaks
Duration h to unload Production Chemicals at delivery location
Capacity Q of truck k to deliver IBCs to location i in week τ

Decision variables:

$X_{ij\tau}$ $= \begin{cases} 1 \\ 0 \end{cases}$ *if a truck drives from location i to location j in week τ*
otherwise

$Y_{i\tau}$ $= \begin{cases} 1 \\ 0 \end{cases}$ *if a truck arrives at location i in week τ*
otherwise

L_{τ} $= \begin{cases} 1 \\ 0 \end{cases}$ *if a truck is used to deliver Production Chemicals in week τ*
otherwise

$U_{i\tau}$ = Integer auxiliary variable nonnegative {1,2,3,..,Q}

$O_{i\tau}$ = Number of orders placed at location i in week τ {0,1,2,3,..., m$_{ij}$}

Objective function:

$$\min z \sum_{\tau=1}^{4}(L_\tau \times (b+r)) + \sum_{i=0}^{61}\sum_{\substack{j=0\\j\neq i}}^{61} X_{ij\tau} \times d_{ij} + \sum_{i=1}^{61} O_{i\tau} \times h)$$

Such that:

$m_{i\tau} = (c_i - (e_{i\tau} - v_{i\tau}))/1000$	$\forall \tau, i$	(1)
$O_{i\tau} \leq m_{i\tau}$	$\forall \tau, i$	(2)
$e_{i\tau} = e_{i,\tau-1} - v_{i\tau} + O_{i,\tau-1} * 1000$	$\forall \tau, i$	(3)
$e_{i\tau} \geq s_i$	$\forall \tau, i$	(4)
$\sum_{i=1}^{61} X_{i0\tau} = L_\tau$	$\forall \tau$	(5)
$\sum_{i=0}^{61} Y_{i\tau} \leq L_\tau$	$\forall \tau$	(6)
$\sum_{\substack{j=0\\j\neq i}}^{61} X_{ij\tau} = Y_{i\tau}$	$\forall \tau, i$	(7)
$O_{i\tau} \leq Y_{i\tau} \times 1000$	$\forall \tau, i$	(8)
$O_{i\tau} \geq Y_{i\tau}$	$\forall \tau, i$	(9)
$\sum_{j=1}^{61} O_{j\tau} \leq Q$	$\forall \tau$	(10)
$X_{ij\tau} + X_{ji\tau} \leq 1$	$\forall \tau, i \geq 1, j \geq 1, j \neq i$	(11)
$\sum_{i=1}^{61} Y_{i\tau} \leq \sum_{j=1}^{61} X_{0j\tau} \times 1000$	$\forall \tau$	(12)
$\sum_{i=1}^{61} Y_{i\tau} \leq \sum_{j=1}^{61} X_{j0\tau} \times 1000$	$\forall \tau$	(13)
$U_{i\tau} - U_{j\tau} + Q * X_{ij\tau} \leq Q - O_{i\tau}$	$\forall \tau, i \geq 1, j \geq 1, j \neq i$	(14)
$O_{i\tau} \leq U_{i\tau} \leq Q$	$\forall \tau, i \geq 1$	(15)
$X_{ij\tau}, Y_{i\tau}, L_\tau, O_{i\tau}, U_{i\tau} \geq 0$	$\forall \tau, i, j$	(16)

The objective function aims to minimize total time required to replenish the injection systems for a period of four weeks. The total replenishment time exists of three components: Truck loading time, travel time between injection systems, and unloading time at injection systems. The first constraint (1) determines the maximum volume of a request. The maximum volume is the maximum inventory level of an injection system minus the inventory level of week (i-1) and the expected consumption of week (i), divided by 1000. The second constraint (2) is a restriction on the requested volume for each injection system. It basically says that the expected inventory level plus the ordered volume cannot exceed the storage capacity of an injection system. Constraint (3) determines the expected inventory level in week (i) by subtracting the consumption in week (i) from the inventory level (i-1) and adding the requested volume for week (i). The inventory level may never fall below the minimum order inventory level and is defined in constraint (4). If we could find a trip from an injection location to the central storage location, a truck is used to deliver Production Chemicals in that specific week, according to Constraint (5). Constraint (6) says that a location can only be visited once during an IBC trip. Constraint (7) makes sure that when a location is visited, the truck should leave from this location to one other location. Constraint (8) confirms that a location should be visited when this location requested for IBCs. On the other hand, constraint (9) does not allow to arrive at a location when no requests have been placed. Constraint (10) limits the total amount of requests in week (i) to 22 IBCs, since this equals the capacity of a truck. Constraint (11) prevents occurrence of return trips between locations. Since we have the same start and end location, a return trip could occur if only one location is replenished. Constraint (12) makes sure that, if there is a request for Production Chemicals, the trip should start at JPB. Constraint (13) obliges the truck to finish at JPB. Constraints (14) and (15) are added to the algorithm to eliminate sub tours disconnected from JPB (Kara, Laporte, & Bektas, 2004). Last constraint (16) ensures that all variables are non-negative.

Estimated Problem Dimensions:

We have an extensive problem, consisting of many variables and constraints. This section discusses the problem dimensions.

Variables

Our model consists of the following indices:

$i, j = 0, \ldots, 61$

$\tau = 1, \ldots, 4$

Given these indices, we are able to calculate the number of variables in our problem. We multiply the indices per decision variable to calculate the total number of variants per decision variable. In Table 6.1, one can find the total number of variables for our problem:

Decision Variables	Indices	Calculation	Number of variables	
$X_{ij\tau}$	τ, i, j	4*62*62	15,376	
$Y_{i\tau}$	τ, i	4*62	248	
L_τ	τ	4	4	
$U_{i\tau}$	$\tau, i \neq 0$	4*61	244	
$O_{i\tau}$	$\tau, i \neq 0$	4*61	244	
Total number of variables:			16,124	

Table 6.1 Problem dimensions

We can reduce the number of variables by adding constraints to the model. In our case, constraints (6) and (8) reduces the scale of the model. Constraint (6) ensures that L_τ becomes 1 if a trip occurs in week τ. This results in a reduction of 4 variables.

$$\sum_{i=1}^{61} X_{i0\tau} = L_\tau \qquad\qquad \forall\, \tau \qquad\qquad (6)$$

Constraint (8) equals decision variable $Y_{i\tau}$ to the sum of all trips from location i to all other locations j. This reduces the number of variables with 248.

$$\sum_{\substack{j=0 \\ j \neq i}}^{61} X_{ij\tau} = Y_{i\tau} \qquad\qquad \forall\, \tau, i \qquad\qquad (8)$$

As a result, our model consists of 15,864 different variables.

Constraints

We also briefly touch upon the number of constraints in our model. The total number of constraints in our model is 31,988, given the indices and constraints described in previous section.

Discussion:

This extensive problem is hard to solve within polynomial time, since it is NP-hard. As described in Chapter 5, we solve this problem using the branch-and-cut algorithm. We cannot solve this problem to optimality within reasonable time, and we therefore insert a time limit to the solver. First, OpenSolver initializes the model, which takes about 1 hour. Second, the model is solved and stops at a predetermined time limit. The model is supposed to be solved once a week and it is desirable to propose a planning within manageable time. After 20 minutes, it takes hours before the model detects minor improvements to the already proposed planning. So, we set the time limit at 20 minutes for solving the problem.

7. Input Chemical Distribution Model

Chapters 5 and 6 extensively reported the current literature regarding our problem and described the model we developed to solve the weekly Chemical Distribution problem. Section 7.1 explains the method to collect the input for the model. Solving the Chemical Distribution Model recurs every week and part of the input data changes in these periods. For the dynamic input data, we focus on the process to obtain the required data and how we progress this information. Section 7.2 discusses the steps to solve the Chemical Deliver Model.

7.1   Data collection

We categorize the input in *fixed* or *dynamic* data. *Fixed* data does not change every week, so these input data should not be updated every week. *Dynamic* data may change daily and does need to be updated every time you solve the Chemical Distribution Model. The Chemical Distribution Model requires the following input data:

		Fixed	Dynamic
Transport data:	Duration d_{ij} to drive from location i to location j	X	
	Duration b to load Production Chemicals at central storage location	X	
	Duration h to unload Production Chemicals at delivery location	X	
	Capacity c_i of storage at location i	X	
	IBCs delivered at location between now and last time the model has been solved		X
	Duration r for a break during the trip	X	
Chemical injection data:	Chemical consumption per Injection Location of last four weeks from now		X
Inventory data:	Last known inventory levels per Injection Location		X
	Maximum replenishment level per Injection Location	X	

The Chemical injection data and Inventory data is used to calculate following parameters:

	Fixed	Dynamic
▪ Minimum order level for Production Chemicals s_i on location i		X
▪ Current inventory level of Production Chemicals e_{i0} at location i		X
▪ Expected injection volume of Production Chemicals in coming weeks, $v_{i\tau}$ location i in week τ		X
▪ Maximum orders to be placed $m_{i\tau}$ for location i in week τ	X	

As one can see, the majority of the input data is dynamic. We previously described that we need to update dynamic input data every week. For this reason, we have already inserted links in Microsoft Excel, which automatically calculate and/or generate the input data. This increases the efficiency and user friendliness of the Chemical Distribution Model. End users only have to download *Chemical consumption data* from an internal source, called Business Objects. To calculate current inventory levels, the Model asks to fill out three different dates: the next Chemical distribution date, the last Chemical distribution date, and the last time the model is solved. The current date is automatically generated. The number of IBCs delivered between now and the last time the model has been solved should be inserted as well. Furthermore, the end user has to manually add the *last measured inventory levels* per Injection Location to the Chemical Distribution Model. This information can be obtained from the last time the Chemical Distribution Model was solved. Operations conduct a physical inventory check every once in a while. To ascertain the reliability of calculated inventory levels, it is highly recommended to update the calculated inventory levels with actual field data from Operations. A dashboard is designed in the Chemical Distribution Model, where the user can add the input for the model.

	Facility	Equipment	Injection skid	Production Chemical	# of IBCs delivered	Inventory level	Date physical inventory level check
1	Bedum	BDM, Topside V31	SKID12 (4m3)	Cortron CK337C50			
2	Grijpskerk 1	GRK1, Waco to Delfzijl	V90	CGO85011			
3	Westerveld	WTV, Wetgas transport	T701 A+B (2.5 m3)	CGO85011			
4	Zevenhuizen 1	ZVH1, Manifold	SKID13 (4m3)	CGO85528			
5	Gasselternijveen 1	GSV1, Outlet_V-60	FRIS013; 3,5 m³	Gyptron SA3420			
6	Gasselternijveen 1	GSV1, Inlet_V-60	FRIS014; 3,5 m³	OS19			
7	Schoonebeek 313	SCH313, Injection in wa	Mother IBC; 1,5 m³	OS19			
8	Schoonebeek 313 Wate	SCH313WD, Water inlet	Mother IBC; 1,5 m³	Bactron UCA495G			
9	Schoonebeek 313 Wate	SCH313WD, Water Inlet	Mother IBC; 1,5 m³	INH 3-6156 (WLoog)			
10	Schoonebeek 313 Wate	SCH313WD, Water inlet	Mother IBC; 1,5 m³	OS19			
11	Schoonebeek 313 Wate	SCH313WD, Water Outl	Mother IBC; 1,5 m³	INH 3-6157 (WZuur)			

Figure 7.1 Chemical Deliver Model input

The fixed input data is acquired from multiple sources. The *durations to travel between locations* is gathered from Google Maps Navigation. Our problem consists of 62 different locations and thus 62 by 62 different travel durations. Manually obtaining duration of each possible tour takes days or even weeks. Therefore, a code is written in Microsoft VBA which automatically acquires the duration between trips and add this to the Chemical Distribution Model. This program is able to automatically download the total durations between trips within two hours. The total duration is calculated for passenger cars. However, the Production Chemicals are delivered with trucks, and some roads are obliged to avoid. Therefore, we assume that travel duration increases with 30% on average, when a truck is used instead of a passenger car. The total travel duration between locations can be found in the Appendices.

Duration for loading a truck for Production Chemicals. Duration to load Production Chemicals at central storage location JPB is assumed to be four hours. This assumption is based on analysis of invoices, where the total duration at a central storage location is specified per trip. The total duration also consists of the average duration to travel from and to base locations. Additional time is required when a trip could not be conducted within one day (11 hours), since the truck drives home and restarts the IBC trip a day after. The invoice also includes this 'additional trip time'. So we also include the average 'additional time' in the *duration for loading a truck*s. *The duration for unloading* Production Chemicals is assumed to be 15 minutes. The assumption for average time to unload IBCs at Production Locations is also based on analysis of invoices from the supplier. On average, a truck driver has a break of 1 hour during the replenishment trip.

The capacity of storage at injection locations depends per location. In Chapter 0, we already touched upon the problems with the reliability of level measurements. The level meters may deviate up to 200 Liters from actual inventory levels for the 4000 L skids. We also have to consider that forecasted injection volumes may be slightly higher than the actual injection volumes. This results in higher inventory levels in coming weeks than expected. To prevent the occurrence of spills during replenishment of inventory, we have decreased the actual storage capacity per location with a certain volume. This volume depends on the potential storage capacity. The maximum replenishment levels are being used as input for capacity, and following capacity levels exist:

Actual storage capacity (L)	Maximum Replenishment levels (L)
4000	3700
3500	3200
2500	2300
1500	1300
1000	900

Table 7.1 Maximum replenishment levels

The dynamic input for parameters is detracted from analysis of the manually acquired dynamic input data. *Current inventory levels* are calculated by subtracting the chemical injection volume between the

date of most recent inventory level update and current date from the most recent inventory level and adding the Chemical volumes delivered in this period.

The *expected injection volumes* in coming periods is based on analysis of Chemical consumption in last weeks. We calculate the average daily injection volume for past four weeks and for last week. As forecast for daily injection volumes in coming period, we take the maximum of the two calculated average daily injection volumes. However, if the average daily injection in last week is more than 1,5 times the average daily injection in last four weeks, we take the average daily injection volume of last week as forecast for coming weeks.

The *minimum order level* varies with the expected injection volumes. The *minimum order level* is at least 200 Liters (safety stock) plus the expected inventory level of one week. Every storage location has a minimum of 200 Liters (safety stock), which is equal to maximum deviation for the measured inventory level from actual inventory level. Appendices show how the dynamic data is automatically generated and displayed in the Chemical Distribution Model.

7.2   Solving the Chemical Distribution Model

We already described the data input for solving the Chemical Distribution Model. Besides the data collection, three additional buttons need to be triggered to solve the Chemical Distribution Model. This Section briefly explains these three steps for solving the model.
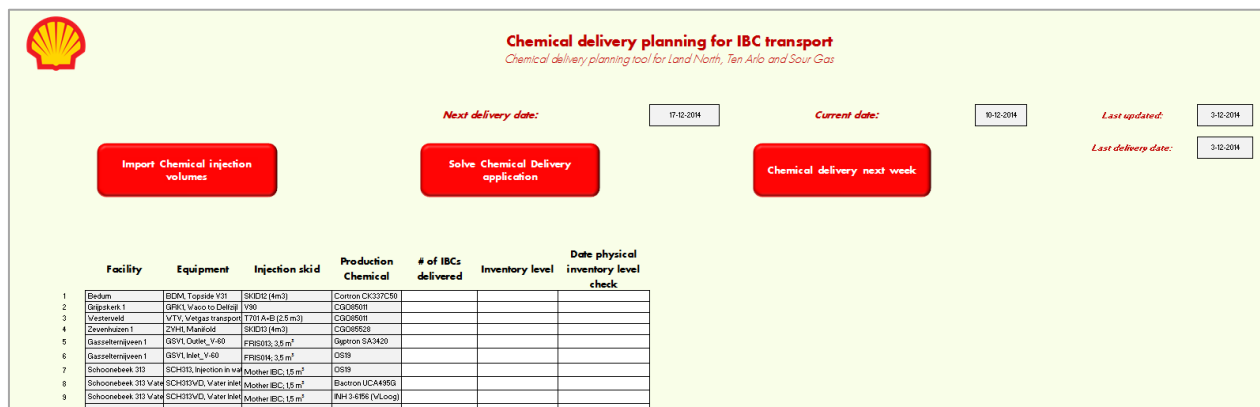
Figure 7.2 Chemical Distribution Model Dashboard

1. *Import Chemical Injection Volumes:* Pressing the first button, automatically uploads the chemical injection volumes of last week in the Chemical Distribution Model. The injection volumes are, as explained obtained from Business Objects.
2. *Solve Chemical Distribution application:* This button solves the model and calculates the most efficient planning for Chemical Distribution Planning in coming four weeks.
3. *Chemical distribution next week:* Pressing this button automatically displays the Chemical Distribution planning for next week, including the most efficient sequence of visits. The expected duration of the trip is also displayed on this sheet.

Before the Chemical Distribution Model can be solved by a user, the Chemical Distribution Model should be installed once by the user. Furthermore, changes to the *fixed data input* may occur. These changes induce minor adjustments to the Chemical Distribution Model. The detailed manuals for (i) installing, (ii) running, and (iii) adjusting the Chemical Distribution Model can be found in the Appendices.

8. Results

Chapter 0 presents the results of the simulation study with the Chemical Distribution Model. The Chemical Distribution Model, described in Chapters 6 and 0, is used to conduct a simulation study over the second semester of 2014. The results of the simulation study demonstrates the reliability and efficiency of the Chemical Distribution Model. Actual Chemical consumption data is used as input data for the Chemical Distribution Model. Section 8.1 shows the results for one run of the Chemical Distribution Model in detail. Section 9.1 presents general results of the complete simulation study.

8.1 Chemical Distribution Model solution

Section 8.1 elaborates on the results of the Chemical Distribution Model, solved on September 17th in 2014. We first acquired and inserted the data which requires manual handlings:

1. Download Chemical injection volumes from Business Object, covering the injection volumes between August 20th – September 17th.
2. Insert requested dates:
   - *Current date:*   17-09-2014
   - *Next delivery date:*   24-09-2014
   - *Last delivery date:*   12-09-2014
   - *Last time model has been solved:*   12-09-2014
3. *Add inventory levels from previously solved Chemical Distribution Model.*
4. *Number of IBCs delivered during the period between now and last time the model was solved.*

Input data from steps 2-4 is inserted in the dashboard of the Chemical Distribution Model, see Figure 8.1. All inventory levels are between the minimum order levels and maximum capacity.
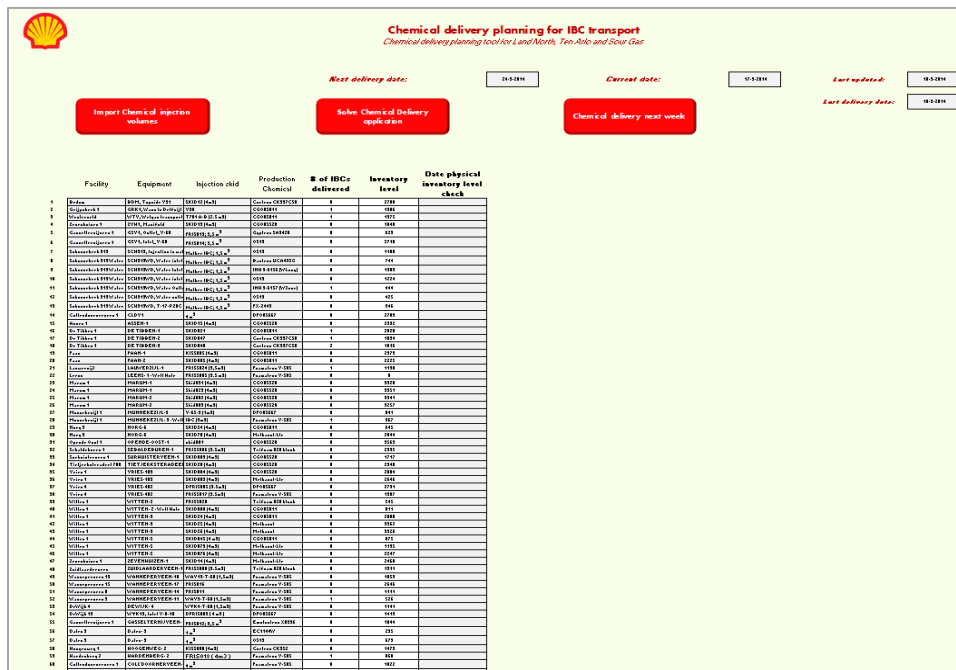
Figure 8.1 Dashboard of Chemical Distribution Model

The next step is to press three buttons subsequently:

1. Press: *Import Chemical Injection Volumes*
2. Press: *Solve Chemical Distribution application*
3. *Chemical distribution next week*

It took the model 1.5 hours to initialize and solve the problem, after which worksheet LocationOutput popped up. This worksheet displays the sequence of locations to be visited with the number of IBCs and Production Chemicals to deliver. The worksheet also provides the expected trip duration. Figure 8.2 illustrates the output of the Chemical Distribution Model on September 17th. The Chemical Distribution Model proposes a distribution of 16 IBCs to 13 different locations in week 12. Total duration of the trip is 13 hours.
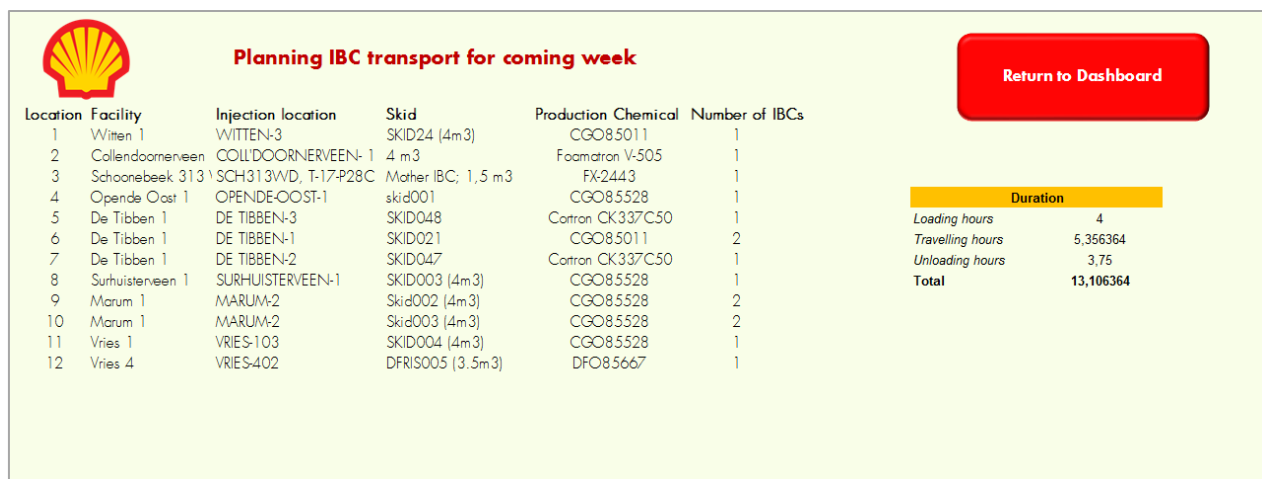
Figure 8.2 Output of Chemical Distribution Model

We have performed a validation study on the outcome provided by the Chemical Distribution Model. First, we have checked whether the solution fulfills the constraints for inventory levels, as can be derived from the Appendices. We can see that the requirements to keep inventory between minimum order level and maximum capacity are satisfied. The calculated expected total duration of the trip is exactly the sum of the loading hours at JPB, the travel duration between the visited locations, and the duration to unload sixteen IBCs at the injection locations, see Figure 8.2. Total capacity of a truck is not exceeded.

We have also validated the proposed route by plotting the proposed vehicle route in Google Maps, see Figure 8.3. The proposed vehicle route seems to make an efficient and viable route, with start and end at the central storage location. There seems to exist a strange sequence for the route from E -> F -> G -> H, but as you can see from Figure 8.4, the varying the sequence of G -> E -> H does not influence the travel time. Other possibly strange sequence is I -> J -> K, for which one may assume that it is a bit faster to change the J -> I. However, this can route is also validated as one can see in Figure 8.4.

Figure 8.3 Route proposed by Chemical Distribution Model
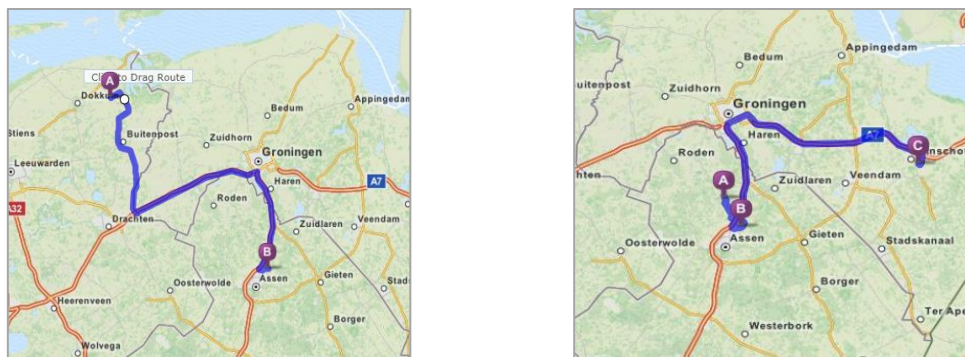
Figure 8.4 Partitioned route I & II

8.2   Simulation study Chemical Distribution Model

Section 8.2 presents the results of the simulation study and compares the results with actual distribution data in 2014. We have conducted 26 experiments to simulate the replenishment of Production Chemicals in the last semester of 2014, starting from June 1st. As we were running the Model, some minor adjustments to the initial Model have been made in the first nine weeks. These adjustments are made in calculation of the chemical injection forecast and determining the injected chemical volume in previous period. The impact of these changes are negligible, so we have decided not to run a new simulation study for the first nine weeks.

Simulation study

The simulation study is conducted using actual Production Chemical data from 2014 as input for the model. Comparing these results with actual transport data in the last semester of 2014 reveals some interesting results. However, we were not able to fully reconstruct the Chemical injection locations in 2014. With the available information, we could only consider the injection points which are still being used with the same Production Chemicals. So, we cover about 90% of the total injection points which were in Production in 2014.

The transport data for Chemical Distribution is acquired from the internal NAM transport dataset. This document covers all transport ordered by the Planning Cell in 2014. Chemical transport data is being filtered from the dataset. From this Chemical transport, we have filtered flat transport to and from the Production Locations with injection skids. The actual transport data delivers to all injection skids which were used in 2014, so it may include trips to injection points which we do not consider in our simulation study. We described in the simulation study that we assume to cover 90% of all injection skids in 2014. Therefore, we assume that 90% of total transport duration is allocated to deliver Production Chemicals to the injection skids in scope of our simulation study.

The results of the simulation study are shown in Table 8.1. As one can see, the simulation study proposes to make 25 trips in the 2nd semester of 2014. This is significantly less than the 38 trips realized in 2014 for distribution of Production Chemicals. Total duration of replenishment is 305 hours. Average costs for hiring a truck in 2014 was €83.60. According to the simulation study, the replenishment costs for Production Chemicals in the 2nd semester of 2014 would be: € 25,450.-. The actual transport data in 2014 shows a total of 477 hours. However, we assume that only 90% of the actual Transport Data is allocated to deliver Production Chemicals to injection skids in scope of this simulation study. We therefore compare the simulation study with 90% of the actual transport data, namely 429 hours. Actual costs for replenishing the injection location in scope of this simulation study were €35,874.-. The simulation study shows a reduction of 29% in replenishment costs for IBCs. The model is developed for Land North, East and Sour Gas and total replenishment costs in 2014 were €87,692.-. The potential costs savings for implementing the Chemical Distribution Model would therefore yield approximately €25,000 for the Northern part of the Netherlands.

	Simulation study		Actual data	
Week nr:	Number of IBCs	Travel duration	Number of trips	Travel duration
27	19	13.71	1	17.5
28	4	8.18	1	17.3
29	9	10.61	4	16.1
30	0	0.00	1	15.8
31	20	14.59	2	15.9
32	6	9.05	2	12.3
33	3	8.07	1	17.0
34	19	17.04	2	24.5
35	22	14.91	1	19.3
36	8	10.02	1	26.6
37	11	12.66	2	23.6
38	15	14.11	2	16.9
39	7	9.80	1	23.1
40	11	13.36	1	19.4
41	6	9.71	1	10.0
42	22	15.27	1	12.7
43	3	8.30	2	12.2
44	14	13.28	1	17.2
45	14	12.47	1	9.6
46	22	16.08	1	23.1
47	11	11.73	1	13.9
48	9	10.56	1	26.9
49	22	16.35	1	23.8
50	8	10.08	2	26.9
51	9	10.55	2	21.8
52	20	14.10	2	13.5
	Total duration:	305	Total duration:	477

Table 8.1 Results simulation study

Model validation

The simulation study is not only used to calculate potential savings using the Chemical Distribution Model. Another important reason to run experiments is to validate the correctness of the model, e.g. whether it satisfies all constraints. We did not identify injection locations facing problems with inventory levels, after the adjustments to the model in week 9. None of the injection locations were running out of stock, or were facing spills during replenishments of Production Chemicals. From these results, we could conclude that the Chemical Distribution Model proposes a sufficient planning for the coming weeks.

We also have to validate the input data for the Planning Model, acquired from Business Objects. We can calculate the expected inventory data with the daily injection volumes extracted from Business Objects. However, we should validate these volume in order to rely on this data. To validate the data, we have asked Operations for actual inventory levels from physical inventory checks. We received

inventory from physical checks in the beginning of July and for August 13th. We have compared the start and end inventory levels by subtracting chemical injection volumes from Business Objects from the start inventory levels. Last, we added the received Production Chemical to the inventory levels and compared the calculated inventory level with the end inventory levels. We could not compare the values for all injection locations, since we only received physical inventory levels for about half of the injection locations. The *Calculated and End inventory levels* gave similar results for the majority of injection locations. We have seen some variations up to 300 Liters for some injection Locations in a period of one month. These variations are the result of inaccurate level meters and the physical inventory checks were executed by two different Operators. So, these variations are not seen as problems and the calculated inventory levels might even be more reliable. However, we recommend Logistics Department to request for the physically checked inventory levels once a month. In this way, we assure that the Planning Model includes the best estimation of inventory levels. Unfortunately, we have found two locations which could not be calculated with data from Business Objects. These locations are:

- Bedum: No reliable flow meter gives a wrong indication of injected Chemical volumes
- Witten-5, Methanol: No data can be extracted for injected Chemical volumes in Business Objects

For these locations, we must calculate expected chemical injection volumes based on historic consumption. These expected injection volumes should be calculated in collaboration with the Process Chemist in charge of these locations, since they are able to calculate the expected Chemical injection based on best estimation.

Conclusion

The Chemical Distribution Model uses a valid algorithm for proposing the optimal IBC schedule. The simulation study proved that the model keeps the inventory levels at injection points within the lowest and highest levels. The input data is also seen as reliable, as long as calculated inventory levels with data from Business Objects is being updated once a month with physically checked inventory levels. The small variation between actual inventory levels and calculated inventory levels cannot be eliminated, due to the inaccuracy in level meters. However, these variations are mitigated in the minimum order levels and maximum replenishment levels, such that the Chemical Distribution Model proposes valid replenishment volumes. According to the simulation study, the annual costs reduction yields €25,000.- for replenishing areas North, Sour Gas, and East.

9. Next steps

Chapter 9 describes the next steps for implementation of the Chemical Distribution Model. This Chapter solely focus on the Chemical Distribution Model and next steps regarding the other issues in the organization of Production Chemicals are described in Chapter 10. The Chemical Distribution Model is developed and we have validated the Model in Chapter 0. Despite the validation study, we do not expected common acceptance to fully rely on the Chemical Distribution Model in first instance. The most important stakeholders regarding the replenishment process are Operations and the Planning Cell (within Logistics). The model should eventually be solved by the Planning Cell and the proposed schedule presented to Operations. The stakeholders should feel comfortable with the solutions of the Model. This takes some time and we therefore recommend to introduce the Chemical Distribution Model in three steps.

9.1   Introduce Chemical Distribution Model to Logistics

First step is to introduce the model within the Planning Cell. The Planning Cell must be trained to use the Chemical Distribution Model on a weekly basis. So, we have developed three manuals for using the Chemical Distribution Model:

    i.   Installing the Chemical Distribution Model on desktop
    ii.   Running the Chemical Distribution Model
    iii.   Adjusting the Chemical Distribution Model

These three manuals can be found in Appendices. The two stakeholders from the Planning Cell already received support for installing and running the Chemical Distribution Model. They are the only stakeholders who must install and run the Model, at this moment. Adjusting the Chemical Distribution Model requires good knowledge of formula's in Excel. The Graduates within the Logistics Department can be seen as Excel gurus and are asked to adjust the model, when sudden changes in the organization occur. We are talking about following changes which require adjustments in the model:

- Adding or deleting an injection location
- Change in (capacity of) storage equipment
- Modifications in formula for expected travel duration
- Change in Minimum order level calculations
- Change in formula to calculate expected injection volume

These are the first steps to introduce the Production Chemicals in the Logistics department. The introduction of the Chemical Distribution Model is in scope of this research.

9.2   Amend requested schedules

The second step introduces the solution of the Chemical Distribution Model to Operations. This step is added to feel comfortable with the Model and its solutions. Operations still request for Chemicals according to their own procedure. Parallel to the requests, the Planning Cell runs the Chemical Distribution Model and compares the proposed schedule with the schedule requested from Operations. The Planning Cell could subsequently propose an amended schedule where some IBCs are added to the trip, or on the other hand are removed from the requested schedule. All amendments to the schedule should be discussed with Operations to create confidence with the Chemical Distribution Model. Once Operations feel comfortable with the calculated inventory levels, it is also useful to share the current inventory levels with Operations. When they have the real time inventory levels, they can minimize the number of visits to (unmanned) injection locations for a check on inventory levels.

9.3   Use Chemical Distribution Model as standard

The last step in implementation insinuates a switch from a reactive to a proactive approach in replenishment planning for the Planning Cell. From this step, the Planning Cell proposes the replenishment schedule based on the solution from the Chemical Distribution Model. The proposed schedule is being reviewed together with Operations. Using the Chemical Distribution Model yields an annual reduction in transport costs of €25,000.-, as described in Chapter 0. Even more beneficial to the organization is that the Chemical Distribution Model eventually results in more stable and reliable insights in inventory levels and expected injection. Better coordination of inventory levels and expected injection minimizes the out of stock probabilities at injection locations. The Chemical Distribution Model also reduces the number of visits to (unmanned) injection locations for physical inventory checks.

10.   Conclusions and recommendations

In this research, we mapped the supply chain organization of Production Chemicals and identified the main issues in this process. Furthermore, we chose to conduct an optimization study for the replenishment of Production Chemicals, which is addressed as one of the issues. This Chapter draws conclusions from the complete research, discusses the results, after which recommendations are provided to eliminate other key issues.

10.1 Conclusions

The objective of this research is to generate a synchronized coordination of the activities, roles and responsibilities throughout the supply chain of Production Chemicals, in order to effectively deploy logistical resources. This objective is deduced from the cohesive sense of unease in the supply chain organization of Production Chemicals, in which different departmental functions are involved. The first observations already confirmed the presumption that a general overview in the Lifecycle of Production Chemicals is missing. We created a general overview by means of data analysis and an overview in the activities, roles and responsibilities in the Production Chemical Lifecycle. As a result, a RACI-matrix for the Production Chemical Lifecycle has been developed which:

- Reduces misunderstandings
- Assigns responsibilities and accountabilities to each role
- Eliminates duplications of effort and spotted gaps
- Improves understanding of cross-functional ways of working across divisions or departments

Overall, this RACI matrix prevents waste activities throughout the supply chain, which relates to the overall objective to deploy logistical resources effectively.

The next step in the research was to analyze the current organization. We identified nine key issues in the Production Chemical Lifecycle from an organizational perspective. We chose for an optimization study to improve coordination in the replenishment of Production Chemicals which need to be injected at production locations. In scope of this optimization study is the replenishment of IBCs to the Northern part of the Netherlands. The objective of the optimization study is to proactively manage the replenishment of Production Chemicals.

In order to realize this objective, we developed a Chemical Distribution Model for the Logistics Planning Cell. The objective of the algorithm used in this Model is to propose Chemical replenishment schedules against minimum total duration. A combination of Rolling Horizon Planning and Travelling Salesman Problem is used to develop the algorithm. Especially with the addition that each location may, or may not be visited makes this variant of Traveling Salesman Problem to the best of our knowledge.

The Chemical Distribution Model is used for the second half of 2014, to calculate potential benefits of this model. The model proved to deliver valid Chemical replenishment schedules, assuring sufficient availability of Production Chemicals on all production locations requiring injection. The simulation

study indicated a reduction of around 29% in transport costs, comparing the results with actual transport data in 2014. Annual costs reduction yields €25,000 in replenishment of Production Chemicals to only the Northern part of the Netherlands. Next to the financial benefits, the proactive approach in replenishment of Production Chemical also yields hard to quantify benefits such as:

- Prevents unplanned gas deferments by minimizing the out of stock probabilities at injection locations
- Eliminates Rush Orders
- Reduces number of visits to (unmanned) injection locations for physical inventory checks

10.2 Recommendations

First recommendation is to add the RACI-matrix to the Corporate Management System (CMS) in order to officially record the Roles & Responsibilities in the Chemical Lifecycle.

Considering the benefits of the Chemical Distribution Model, we recommend the Logistics Department to start a trial soon, following the implementation plan described in Chapter 9. The Chemical Distribution Model is developed for the Northern part of the Netherlands. Replacing the input data with data from area West result in an additional Chemical Distribution Model for Area West. We recommend to develop the Chemical Distribution Model for Area West as soon as the current Chemical Distribution Model is successfully implemented and widely accepted within the organization. This Chemical Distribution Model yields the same benefits as those of Area North. However, we expect to realize a smaller cost reduction for area West, in terms of percentage, since Area West comprehends less Injection Locations. The Chemical Distribution Model yields more financial benefits when it involves more locations, since there is a higher probability to utilize full truck capacity. Nevertheless, even with a conservative assumption that the Chemical Distribution Model for Area West yields a cost reduction of 20%, the annual cost savings are €15,000.-.

The following recommendations relate to the other key issues addressed in the organization. We only recommend to solve those issues where perceived impact is more important than associated investment costs.

Chapter 3.2 already discussed the unclarity in ownership of the QA/QC of mixed Production Chemicals, delivered at production locations requiring Chemicals. Despite the serious concerns regarding the quality of mixed Production Chemicals, no one is accountable for the QA/QC. Worst case scenario is that poor quality of Production Chemical mixes result in gas deferments, or harmed equipment.

Process Chemistry calculates the recommended dose and mix rates and are aware of the consequences for under and over injection of Production Chemicals. Process Chemistry is also the appropriate department for proposing a sufficient solution when the assessed quality of mixed Production Chemical is not within the acceptable range. We therefore recommend to start QA/QC

by Process Chemistry to ascertain the quality of mixed Production Chemicals. This should then also be added to the RACI-matrix, see Table 10.1.

Action	Production Chemistry			C & P	Operations	Logistics	JPB	Vendor	Legal department
	PCT	CMT	Contract holder		Plant rep.	Planning Cell	Mixing location	(In) Direct delivery	Legal
.....									
Assess quality of delivered Chemical mixes at Injection Locations	EXE				INF	INF	INF		

Table 10.1 Recommended Roles & Responsibilities QA/QC

We basically see two opportunities to ascertain the quality of Production Chemicals. The easiest way to assure the minimum Production Chemical volumes are injected is to directly increase either the recommended dose rate, or the mix rate for a Production Chemical mix. This may eliminate the concerns regarding the injection of a minimum concentration Production Chemical at any time. The costs to increase dose rates or mix rates are also relatively low. However, it is from environmental perspective not desired to increase injection volumes of Chemicals. Especially not with the recent media attention regarding the water injection in Twente.

Other option to start with QA/QC is to take random samples and analyze the quality of the mixed Production Chemicals delivered at injection locations. The analysis and consequences for possible outcomes are described in Figure 10.1.
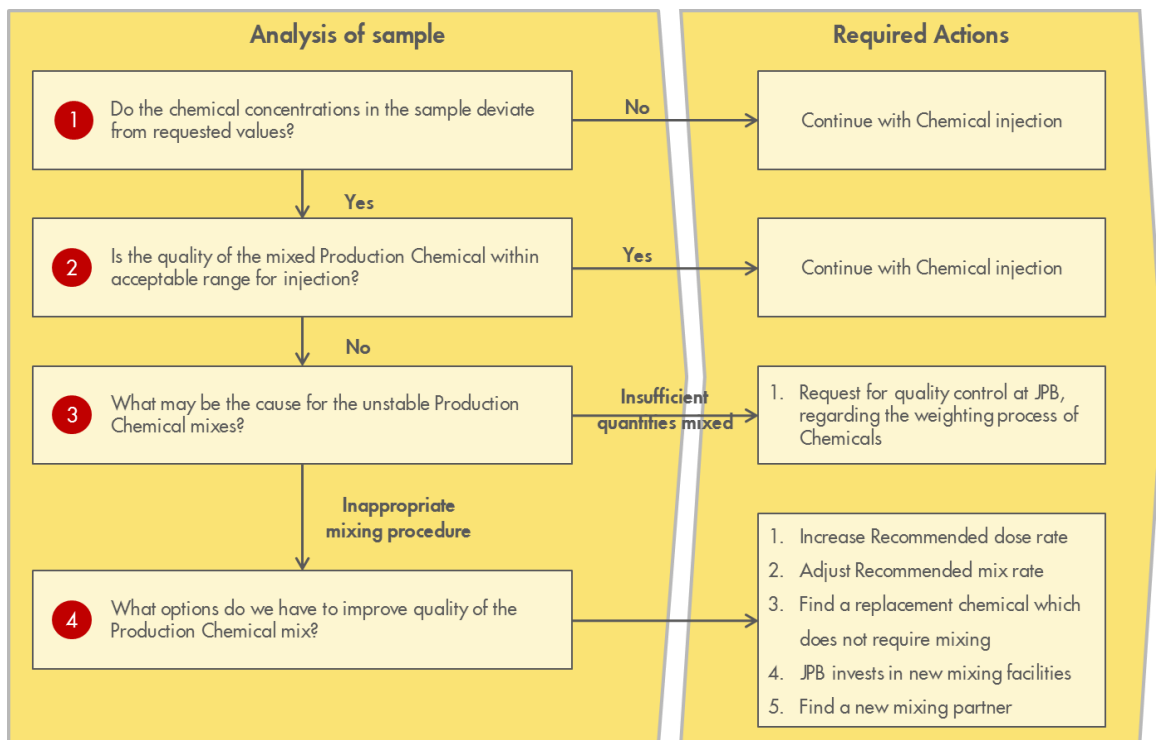
Figure 10.1 Analysis and consequences for results of sampling

The advantage of random sampling is that we have a good indication of the variances in injected Production Chemical concentrations and do only adjust those Production Chemical mixes which show high variations within a batch.

We touched upon the management of central inventories throughout the end to end supply chain. There is no clear procedure for central inventory management and roles & responsibilities are not clearly defined. Uncoordinated management of inventory increases the out of stock probability. We therefore recommend to develop a standard procedure regarding management of central inventories throughout the end to end supply chain. We suggest to develop a standard procedure in terms of Roles & Responsibilities and for determining minimum and maximum inventory volumes. Questions to be answered per type of Production Chemicals are typically:

- What volumes do we want on stock?
- What is the most efficient Inventory Location to store this Production Chemical?
- What are the reorder points?
- What are reorder volumes?

Last recommendation relates to the data inconsistencies, described in Chapter 3.3. Latest developments in legislation makes it more and more important to improve traceability of Production Chemicals. It is therefore recommended to investigate the opportunities to amend the set-up in SAP, such that order quantities from Operations are recorded in one unique measuring unit (e.g. Liters). We also recommend to improve Transport data and allocate travel duration to all visited locations in a trip. Last recommendation regarding the data is to investigate the possibilities for adding a ´key´ to Transport data, for example the order number. This key aims to match different datasheets, for example the Transport data and Ordering data. This improves the traceability of Production Chemicals and allows a more detailed analysis in Production Chemicals.

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Appendices

Appendix 1: Suppliers

The NAM orders Production Chemicals from different suppliers. Following organizations are used as supplier between 2011 – 2014. Two of NAMs largest Chemical suppliers, Nalco and Champion Technology, merged recently.

Supplier	Product groups
Nalco	Corrosion inhibitors
	Solvent chemicals
	Scale inhibitors
	Kinetic Hydration Inhibitors
	H2S Scavengers
Helm AG	Methanol
Univar Zwijndrecht	Glycol
	Methanol
	Demi water
	Sodium hydroxide
	Miscellaneous
	Anti-freeze
Shell Chemicals	Glycol
Peterson Den Helder BV	Methanol
Baker Petrolite	Liquid unloading
	Demulsifier
	Corrosion inhibitor
	Scale inhibitor
	Water treatment
	Kinetic Hydration Inhibitors
Oliecentrale Nederland BV	Anti-freeze (coolant)
Champion Technologies	Water treatment
	Demulsifier
	Corrosion inhibitor
	Scale inhibitor
	Miscellaneous
	Liquid unloading
	H2S Scavenger
Made by NAM	Glycol

Appendix II: Packaging Materials

Bulk transport

Bulk tanks are being used for high volume transport. Bulk transport is supplied from road containers or from special tanks in the vessels. Bulk containers are mainly used for storage and transportation of the Production Chemicals from supplier or storage location to the location where the chemicals are mixed and packaged. Some locations have such an high demand for certain Production Chemicals that those locations can be supplied with bulk packages. These are most likely the offshore locations.

IMOs

IMOs are used at offshore locations and are easy to transport on vessels. IMOs used by the NAM can be found in two standard measures of 2.5 m3 and 4.5 m3. The IMOs are hired at Reym in Beverwijk with a standard rental costs of €30,- a day.

IBCs

Intermediate Bulk Containers (IBCs) are mainly used at onshore production locations and have a capacity of 1000l. We often see that the Production Chemicals received in bulk containers from the supplier, are repackaged to IBCs. These IBCs are easy to connect to their mother IBCs on site, from which the Production Chemicals are injected. Two different types of IBCs are used during the process. NAM owns several stainless steel IBCs, used as packaging material when Production Chemicals are mixed at JPB Farmsum. Some of the suppliers deliver the Production Chemicals in plastic IBCs rather than bulk and those IBCs are sold to Jager BV after a while.

Drums

Iron drums are used for a chemical mix requiring a low concentration of a certain Production Chemical, or for Production Chemicals which are requested in low volumes. Typical volume of a drum is 200l and the drums are disposed as waste after injection of Production Chemicals.

Cans

Production Chemicals which are rarely requested in low volumes or in low concentrations are supplied in cans. The cans are delivered by the supplier of Production Chemicals, or bought externally, and occurs in varying volumes of 10l, 20l, or 25l. Once the Production Chemicals are injected, the cans are disposed as waste.

Bottles

One of the frequently ordered Production Chemicals, the oxygen scavenger, is supplied in small bottles of 1l, which are disposed as waste after injection.

Tank transport

Road tankers are used for onshore bulk transport. Road tankers could vary in size and numbers of (closed) compartments. A tanker with multiple compartments is capable to transport multiple Production Chemicals in one trip. The road tanker is being used to deliver bulk at a storage location from which it could be packed in IBCs, drums or cans. In some cases, the road tanker delivers Production Chemicals to a production location.

Flat transport

Production Chemicals which cannot be transported in road tankers are supplied with road trailers. IBCs, IMOs, cans, drums and bottles are supplied from trailers. These trailers are used for transportation of raw chemicals to storage locations and to supply chemical mixes to the production locations.

Vessel

A vessel is used for offshore transport of Production Chemicals. IMOs and bulk are the main forms of supply. However, the offshore platforms are fully supplied by vessels, so all types of packaging material can be delivered at the platforms.

Appendix III: Additional internal transport (DDP)

Supplier	Main product	Storage	Internal handling costs	
			Storage & Handling	Transport
Helm AG	Methanol Bulk	Caldic Rotterdam	-	-
Nalco	EC9386-a	Reym Emmen	Emmen	-
	EC1610-a	CTT Rotterdam	Rental tank in Rotterdam	-
	EC6671-a	CTT Rotterdam	Rental tank in Rotterdam	Cisterna (IT)–Rotterdam
	Others	JPB	JPB	-
Halliburton	Empty IMOs	Den Helder	-	Beverwijk–Den Helder
	Cleaning of IMOs	IJmuiden	-	Beverwijk–IJmuiden–Den Helder
	IMOs with Brine	Emmen	-	Beverwijk–Emmen-Den Helder
Baker		JPB	JPB	
Shell	CGO 85011	Gouda		Gouda-Tankenpark
	MEG and DEG 85% - 15%	Tankenpark Delfzijl	Tankenpark	Moerdijk–Zwijndrecht-Delfzijl
	100% MEG	JPB	JPB	Moerdijk–Farmsum-Winschoten
	TEG	Peterson chemicals	Den Helder	
Univar	Others	JPB	JPB	Zwijndrecht–JPB
	Sodium Hydroxide 18%	Zwijndrecht	-	-
Champion tech	CK352	Reym Emmen	Reym Emmen	Delden-Emmen
	CK-337-C50	JPB	Reym Emmen	Delden–Emmen-JPB
	CK-337-C50	Tankenpark	Reym Emmen/Tankenpark	Delden-Emmen-Tankenpark
	X-8067/UCA-495G/OS-19	OWT	-	-
	Others	JPB	JPB	-
Oliecentrale	DPP	OCN	-	-
		JPB	JPB	JPB – Den Helder
Peterson Den Helder b.v.	Methanol	Den Helder	Den Helder	
Peterson chemicals	Methanol	Den Helder	Den Helder	
NAM Offshore	Regenerated MEG	JPB	JPB	Den Helder-Helmond-JPB

Appendix IV: Storage and handling

Most of the Production Chemicals are mixed at the mixing location of JPB in Farmsum. However, this location is not certified for storage of Production Chemicals. The process is visualized in following graph:
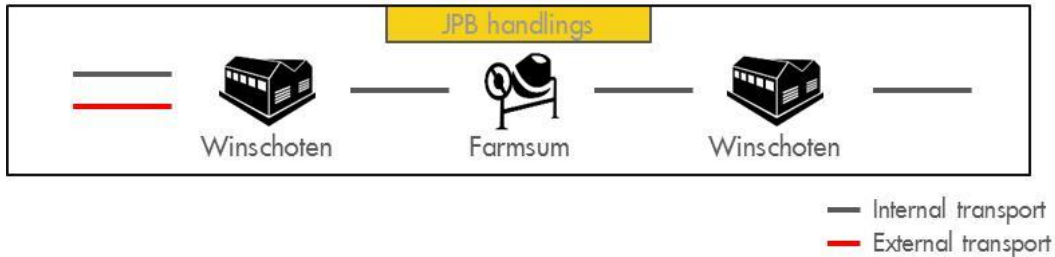
First, the raw chemicals are delivered to the warehouse of JPB in Winschoten. When the Logistics Department receives a request for Production Chemicals from the Production Location, the raw chemicals are transported to Farmsum to produce the desired Production Chemical. Once a week on Friday, one truck picks up the chemicals in Winschoten, needed at Production Locations in the next week and drives to Farmsum on the following Monday, where the chemicals are mixed. The final Production Chemicals are being send back to Winschoten on Tuesday. The Special requests for Production Chemicals, such as rush orders, or bulk mixes, are transported by other trucks. Since the location in Farmsum is not certified to store chemicals, the batch with Production Chemicals returns to Winschoten, where they can be stored until delivery at the Production well. We give a graphic representation of this process below:
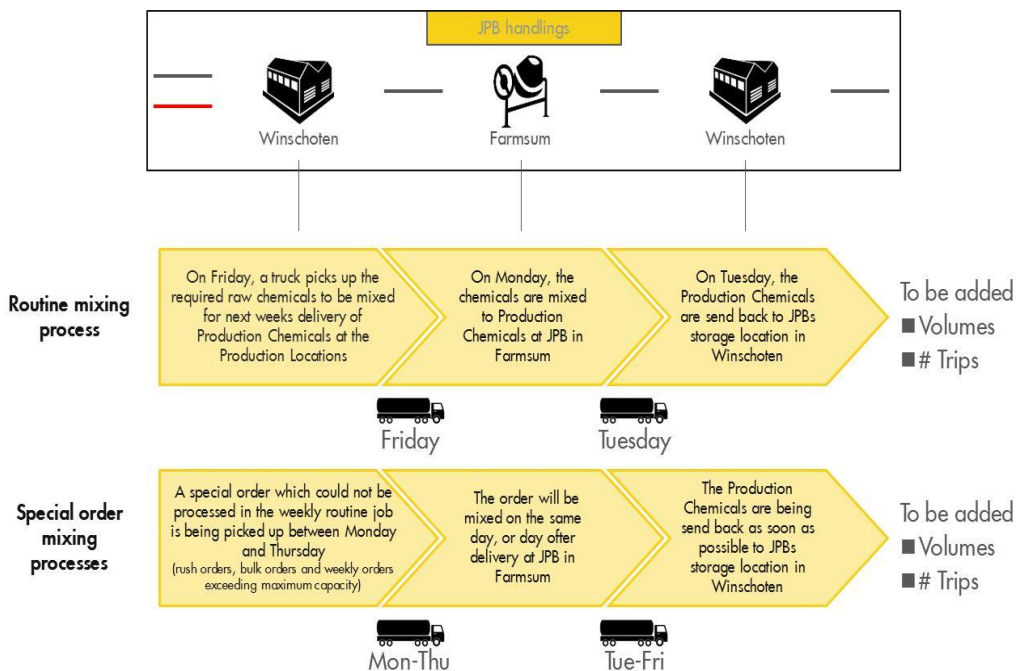
Appendix V: Distances between locations

i	Calculate Duration	1	2	3	4	5	6	7	8	9	10	11
		A.J. Romijnweg 30	Wolddijk 37, BEDUM	Waardweg 3A, GRIJP	Weg voor de Binnenv	Oudestreek, ZEVENH	Gasselternijveenschee	Gasselternijveenschee	Katshaarweg, Coevor	Katshaarweg, Coevor	Katshaarweg, Coevor	Katshaarweg, Coevor
1	A.J. Romijnweg 30, Winschoten	0	0,6014	0,7808	0,5363	0,7286	0,4119	0,4119	0,9803	0,9803	0,9803	0,9803
2	Wolddijk 37, BEDUM	0,6014	0	0,50361	0,76417	0,62778	0,7347	0,7347	1,1775	1,1775	1,1775	1,1775
3	Waardweg 3A, GRIJPSKERK	0,7808	0,515	0	0,85472	0,40139	0,8322	0,8322	1,2725	1,2725	1,2725	1,2725
4	Weg voor de Binnenvelden, Grolloo	0,5363	0,7972	0,8589	0	0,65444	0,4278	0,4278	0,685	0,685	0,685	0,685
5	Oudestreek, ZEVENHUIZEN	0,7286	0,6222	0,3364	0,64528	0	0,8028	0,8028	1,1161	1,1161	1,1161	1,1161
6	Gasselternijveenschedreef, GASSELTERNIJVEEN	0,4119	0,79972	0,87056	0,42222	0,81083	0	0	0,7011	0,7011	0,7011	0,7011
7	Gasselternijveenschedreef, GASSELTERNIJVEEN	0,4119	0,79972	0,87056	0,42222	0,81083	0	0	0,7011	0,7011	0,7011	0,7011
8	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
9	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
10	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
11	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
12	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
13	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
14	Katshaarweg, Coevorden	1,0233	1,2017	1,2811	0,7211	1,1283	0,7034	0,7034	0	0	0	0
15	Slagenweg, Collendoornerveen	1,0553	1,1822	1,2617	0,7775	1,0663	0,7642	0,7642	0,3622	0,3622	0,3622	0,3622
16	Asserwijk, ASSEN	0,6292	0,61528	0,67634	0,2875	0,42633	0,46	0,46	0,7697	0,7697	0,7697	0,7697
17	Tibsterwei 4E	1,0519	0,6369	0,315	1,12583	0,6725	1,1633	1,1633	1,5444	1,5444	1,5444	1,5444
18	Tibsterwei 4E	1,0519	0,6369	0,315	1,12583	0,6725	1,1633	1,1633	1,5444	1,5444	1,5444	1,5444
19	Tibsterwei 4E	1,0519	0,6369	0,315	1,12583	0,6725	1,1633	1,1633	1,5444	1,5444	1,5444	1,5444
20	Fanerweg, FAAN	0,6342	0,36833	0,20306	0,67361	0,34611	0,7111	0,7111	1,0319	1,0319	1,0319	1,0319
21	Fanerweg, FAAN	0,6342	0,36833	0,20306	0,67361	0,34611	0,7111	0,7111	1,0319	1,0319	1,0319	1,0319
22	Stadsweg, LAUWERZIJL	0,8375	0,51639	0,10056	0,91139	0,45806	0,3489	0,3489	1,33	1,33	1,33	1,33
23	Klaarkampenweg, LEENS	0,7919	0,34083	0,32028	0,92889	0,67778	0,3664	0,3664	1,3475	1,3475	1,3475	1,3475
24	Leidijk 6, MARUM	0,7042	0,59806	0,38361	0,74083	0,28111	0,7783	0,7783	1,1617	1,1617	1,1617	1,1617
25	Leidijk 6, MARUM	0,7042	0,59806	0,38361	0,74083	0,28111	0,7783	0,7783	1,1617	1,1617	1,1617	1,1617
26	Leidijk 6, MARUM	0,7042	0,59806	0,38361	0,74083	0,28111	0,7783	0,7783	1,1617	1,1617	1,1617	1,1617
27	Leidijk 6, MARUM	0,7042	0,59806	0,38361	0,74083	0,28111	0,7783	0,7783	1,1617	1,1617	1,1617	1,1617
28	Stadsweg 37, MUNNEKEZIJL	0,8356	0,54194	0,03861	0,90944	0,45611	0,3463	0,3463	1,3278	1,3278	1,3278	1,3278
29	Stadsweg 37, MUNNEKEZIJL	0,8356	0,54194	0,03861	0,90944	0,45611	0,3463	0,3463	1,3278	1,3278	1,3278	1,3278
30	Middendrift, NORG	0,7614	0,66556	0,47134	0,61722	0,08134	0,7458	0,7458	1,0972	1,0972	1,0972	1,0972
31	Middendrift, NORG	0,7614	0,66556	0,47134	0,61722	0,08134	0,7458	0,7458	1,0972	1,0972	1,0972	1,0972
32	Kolonieweg, OPENDE	0,7164	0,6139	0,38139	0,75306	0,28472	0,7906	0,7906	1,1722	1,1722	1,1722	1,1722
33	Caspar Roblesdijk, SEBALDEBUREN	0,7828	0,61111	0,25028	0,81344	0,36611	0,8563	0,8563	1,2364	1,2364	1,2364	1,2364
34	Dalweg, SURHUISTERVEEN	0,7861	0,68	0,33278	0,82278	0,36306	0,8603	0,8603	1,2431	1,2431	1,2431	1,2431
35	Hamsterpein, TIETJERKSTERADEEL	0,8897	0,74278	0,31806	0,92639	0,46667	0,9639	0,9639	1,2983	1,2983	1,2983	1,2983
36	Het Kleuveveld 2a, VRIES	0,6383	0,62083	0,6825	0,37444	0,43634	0,5211	0,5211	0,8558	0,8558	0,8558	0,8558
37	Het Kleuveveld 2a, VRIES	0,6383	0,62083	0,6825	0,37444	0,43634	0,5211	0,5211	0,8558	0,8558	0,8558	0,8558
38	Kampweg, VRIES	0,7117	0,62556	0,60722	0,475	0,325	0,5592	0,5592	0,9406	0,9406	0,9406	0,9406
39	Kampweg, VRIES	0,7117	0,62556	0,60722	0,475	0,325	0,5592	0,5592	0,9406	0,9406	0,9406	0,9406
40	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
41	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
42	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
43	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
44	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
45	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
46	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
47	Witterbroek, WITTEN	0,5769	0,62778	0,68944	0,23917	0,48528	0,4078	0,4078	0,7147	0,7147	0,7147	0,7147
48	Oudestreek, ZEVENHUIZEN	0,7286	0,62222	0,33639	0,64528	0	0,8028	0,8028	1,1161	1,1161	1,1161	1,1161
49	Broekdijk, ZUIDLAARDERVEEN	0,5044	0,61056	0,71972	0,39917	0,66	0,3706	0,3706	0,7897	0,7897	0,7897	0,7897
50	Ruinerwoldseweg, WANNEPERVEEN	1,0147	1,07444	0,91806	0,65056	0,82833	0,8456	0,8456	0,6463	0,6463	0,6463	0,6463
51	De Veltkamp, Rogat	0,9828	1,0281	0,97389	0,61833	0,88389	0,8136	0,8136	0,5744	0,5744	0,5744	0,5744
52	Gedeputeerde Dekkerweg, WANNEPERVEEN	1,0844	1,14417	0,915	0,72028	0,825	0,9153	0,9153	0,7119	0,7119	0,7119	0,7119
53	Haakswold, ruinerwold	1,0028	1,0483	0,34833	0,63861	0,85861	0,8336	0,8336	0,6667	0,6667	0,6667	0,6667
54	Koekangerdwarsdijk, DE WIJK	0,9278	0,9875	1,01944	0,56361	0,85444	0,7586	0,7586	0,63	0,63	0,63	0,63
55	Koekangerdwarsdijk, DE WIJK	0,9278	0,9875	1,01944	0,56361	0,85444	0,7586	0,7586	0,63	0,63	0,63	0,63
56	Gasselternijveenschedreef, GASSELTERNIJVEEN	0,4119	0,79972	0,87056	0,42222	0,81083	0	0	0,7011	0,7011	0,7011	0,7011
57	Burgemeester Ten Holteweg, DALEN	0,8917	1,10889	1,17056	0,61	0,9875	0,5394	0,5394	0,2683	0,2683	0,2683	0,2683
58	Burgemeester Ten Holteweg, DALEN	0,8917	1,10889	1,17056	0,61	0,9875	0,5394	0,5394	0,2683	0,2683	0,2683	0,2683
59	Hoekweg, Hoogenweg	1,0308	1,2317	1,3711	0,8128	1,2189	0,7934	0,7934	0,3375	0,3375	0,3375	0,3375
60	Zwarte Dijk, Lutten	1,0714	1,1636	1,2431	0,7589	1,0483	0,7803	0,7803	0,3783	0,3783	0,3783	0,3783
61	Slagenweg, Collendoornerveen	1,0553	1,1822	1,2617	0,7775	1,0663	0,7642	0,7642	0,3622	0,3622	0,3622	0,3622
62	Kerkenkastweg, Den Velde	1,065	1,2658	1,3453	0,7863	1,1931	0,7736	0,7736	0,3717	0,3717	0,3717	0,3717

Appendix VI: Dynamic input data Chemical Distribution Model

Calculated dynamic variables												
Facility	**Average daily injection**	**Capacity (Cj)**	**Expected Consumption (Vij)**				**Safety inventory level (Sj)**	**Expected inventory level (Iij)**				
			Week 1	*Week 2*	*Week 3*	*Week 4*		*0*	*1*	*2*	*3*	*4*
Bedum	239	3700	1.675	1.675	1.675	1.675	1.875	3.700	4.024	4.349	3.674	2.999
Grijpskerk 1	62	3700	431	431	431	431	631	2.833	2.402	1.972	1.541	1.111
Westerveld	24	2300	168	168	168	168	368	1.425	1.257	2.089	2.921	2.753
Zevenhuizen 1	54	3700	379	379	379	379	579	970	591	212	-167	-547
Gasselternijveen 1	2	3200	16	16	16	16	216	438	423	407	392	376
Gasselternijveen 1	7	3200	51	51	51	51	251	2.117	2.066	2.015	1.964	1.913
Schoonebeek 313	4	1300	26	26	26	26	226	1.282	1.255	1.229	1.203	1.176
Schoonebeek 313 Water Disposal	1	1300	8	8	8	8	208	630	622	614	606	598
Schoonebeek 313 Water Disposal	10	1300	68	68	68	68	268	466	398	329	261	192
Schoonebeek 313 Water Disposal	13	1300	91	91	91	91	291	968	876	785	693	1.602
Schoonebeek 313 Water Disposal	16	1300	112	112	112	112	300	536	424	312	200	88
Schoonebeek 313 Water Disposal	6	1300	39	39	39	39	239	1.241	1.202	1.163	1.124	1.085
Schoonebeek 313 Water Disposal	5	1300	37	37	37	37	237	874	837	799	762	725
Collendoornerveen 1	0	3700	0	0	0	0	200	2.709	2.709	2.709	2.709	2.709
Assen 1	0	3700	0	0	0	0	200	2.392	2.392	2.392	2.392	2.392
De Tibben 1	91	3700	634	634	634	634	834	3.382	2.748	4.114	3.480	2.846
De Tibben 1	59	3700	414	414	414	414	614	2.436	2.022	1.609	1.195	782
....	....	....	....	....	....	....	....	....	....	....	....	....

Appendix VII: Chemical Distribution Model solution
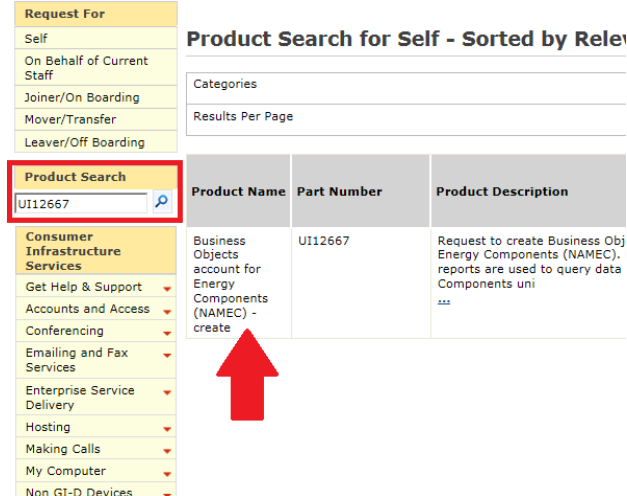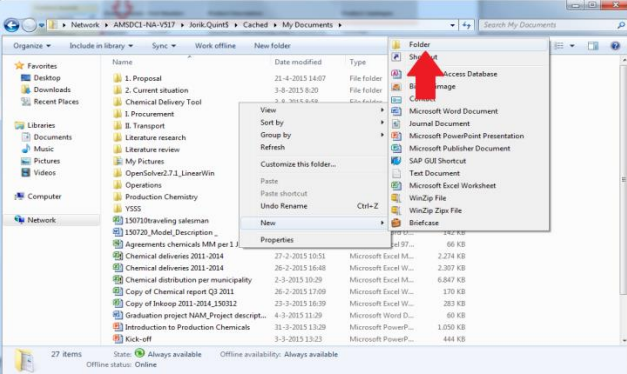
Facility	Max. capacity	Replenish. level	Consumption				Safety level	Calculated inventory	
			Week 1	*Week 2*	*Week 3*	*Week 4*		*0*	*1*
Bedum	4000	3700	88	88	88	88	376	2.788	2.700
Grijpskerk 1	4000	3700	214	214	214	214	414	2.787	2.572
Westerveld	2500	2300	398	398	398	398	598	2.004	1.606
Zevenhuizen 1	4000	3700	0	0	0	0	200	1.048	1.048
Gasselternijveen 1	3500	3300	15	15	15	15	215	615	600
Gasselternijveen 1	3500	3300	45	45	45	45	245	2.667	2.622
Schoonebeek 313	1500	1300	23	23	23	23	223	1.165	1.142
Schoonebeek 313 Water Disposal	1500	1300	3	3	3	3	206	744	741
Schoonebeek 313 Water Disposal	1500	1300	19	19	19	19	239	1.300	1.281
Schoonebeek 313 Water Disposal	1500	1300	142	142	142	142	300	1.082	940
Schoonebeek 313 Water Disposal	1500	1300	20	20	20	20	240	1.300	1.280
Schoonebeek 313 Water Disposal	1500	1300	8	8	8	8	217	425	416
Schoonebeek 313 Water Disposal	1500	1300	37	37	37	37	237	309	1.272
Collendoornerveen 1	4000	3700	0	0	0	0	200	2.709	2.709
Assen 1	4000	3700	0	0	0	0	200	2.392	2.392
De Tibben 1	4000	3700	702	702	702	702	902	2.344	1.642
De Tibben 1	4000	3700	506	506	506	506	706	1.539	2.033
De Tibben 1	4000	3700	952	952	952	952	1.152	2.899	2.947
Faan	4000	3700	549	549	549	549	749	2.424	2.875
Faan	4000	3700	0	0	0	0	200	2.225	2.225
Lauwerzijl	3500	3300	0	0	0	0	200	2.138	2.138
Leens	3500	3300	0	0	0	0	2.300	2.300	2.300
Marum 1	4000	3700	487	487	487	487	687	2.942	2.455
Marum 1	4000	3700	487	487	487	487	687	2.965	2.478
Marum 1	4000	3700	898	898	898	898	1.098	2.496	3.598
Marum 1	4000	3700	898	898	898	898	1.098	2.412	3.514
Munnekezijl 1	2000	1800	0	0	0	0	200	841	841
Munnekezijl 1	3000	2700	0	0	0	0	200	1.367	1.367
Norg 3	4000	3700	0	0	0	0	200	645	645
Norg 3	4000	3700	0	0	0	0	200	2.044	2.044

Opende Oost 1	4000	3700	843	843	843	843	1.043	2.720	2.877
Sebaldeburen 1	3500	3200	164	164	164	164	528	2.935	2.772
Surhuisterveen 1	4000	3700	298	298	298	298	498	1.508	2.210
Tietjerksteradeel 700	4000	3700	389	389	389	389	589	1.959	2.570
Vries 1	4000	3700	1.044	1.044	1.044	1.044	1.244	1.840	2.796
Vries 1	4000	3700	0	0	0	0	200	2.646	2.646
Vries 4	3500	3300	489	489	489	489	689	2.302	1.814
Vries 4	3500	3300	49	49	49	49	249	1.858	2.809
Witten 1	3500	3300	0	0	0	0	200	545	545
Witten 1	4000	3700	0	0	0	0	200	811	811
Witten 1	4000	3700	526	526	526	526	726	2.274	2.748
Witten 1	4000	3700	0	0	0	0	200	3.362	3.362
Witten 1	4000	3700	0	0	0	0	200	3.326	3.326
Witten 1	4000	3700	0	0	0	0	200	875	875
Witten 1	4000	3700	0	0	0	0	200	1.195	1.195
Witten 1	4000	3700	0	0	0	0	200	2.247	2.247
Zevenhuizen 1	4000	3700	0	0	0	0	200	2.460	2.460
Zuidlaarderveen	3500	3200	0	0	0	0	200	1.311	1.311
Wanneperveen 13	1500	1300	37	37	37	37	246	1.025	988
Wanneperveen 15	3500	3200	24	24	24	24	230	2.628	2.604
Wanneperveen 8	3500	3200	72	72	72	72	272	966	894
Wanneperveen 9	1500	1300	162	162	162	162	300	1.300	1.138
DeWijk 4	1500	1300	0	0	0	0	200	1.141	1.141
DeWijk 13	4000	3700	86	86	86	86	286	1.333	1.247
Gasselternijveen 1	3500	3300	195	195	195	195	395	1.662	1.467
Dalen 9	2000	1300	0	0	0	0	200	295	295
Dalen 9	2000	1300	0	0	0	0	200	673	673
Hoogenweg 1	4000	3700	11	11	11	11	211	1.470	1.459
Hardenberg 2	4000	3700	149	149	149	149	349	1.761	1.611
Collendoornerveen 1	4000	3700	230	230	230	230	430	792	1.562
Den Velde 1	3500	3300	42	42	42	42	242	2.515	2.473

Appendix VIII: Manual for installing the Chemical Distribution Model

This manual is developed to prepare you for using the Chemical Distribution Model. In order to run the Chemical Distribution Model, a program called OpenSolver need to be installed. You also need a license for Business Object to download the Chemical injection volumes per injection point. Last, we need to configure some personal settings, such that the Chemical Distribution Model could automatically upload data. Once you have completed the following steps, you are able to run the Chemical Distribution Model:

Step	Description	Screenshots /details
0.	Send MyRequest for Business Objects account for Energy Components (NAMEC)-create	
0.1	Go to: http://sww-myrequest.shell.com/Pages/NewEPRM_Home.aspx	
0.2	Enter Product Search: UI12667	
0.3	Add to shopping cart: Business Objects account for Energy Components (NAMEC) – create	
1.	Create a new folder called "Chemical Delivery Model" in My documents (\\AMSDC1-NA-V517\"FirstName.LastName"$\Cached\My Documents\ Chemical Delivery Tool)	
1.1	Go to: Documents -> My Documents o Quick link to this map (Adjust **local code and your name** first):	\\AMSDC1-NA-**V517\Jorik.Quint**$\Cached\My Documents\ >>>>Adjust **local code and your name** to personal settings <<<<
1.2	Right mouse click: New -> Folder	

1.3	Rename Folder into: Chemical Delivery Tool o Right Mouse Click: Rename	
2. Download OpenSolver (required to run the Planning Tool)		
2.1	Go to: http://sourceforge.net/projects/opensolver/files/latest/download o Press Open to download OpenSolver	http://sourceforge.net/projects/opensolver/files/latest/download
2.2	WinZip opens after completion o Go to: Winzip Folder o Press: Unzip To...	
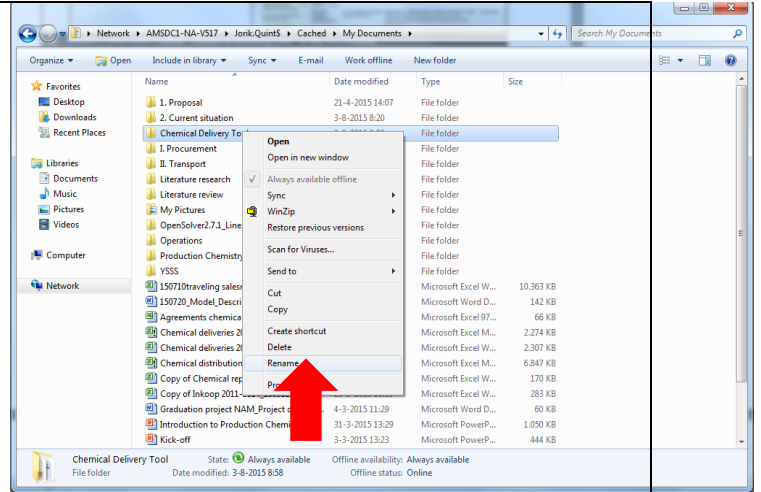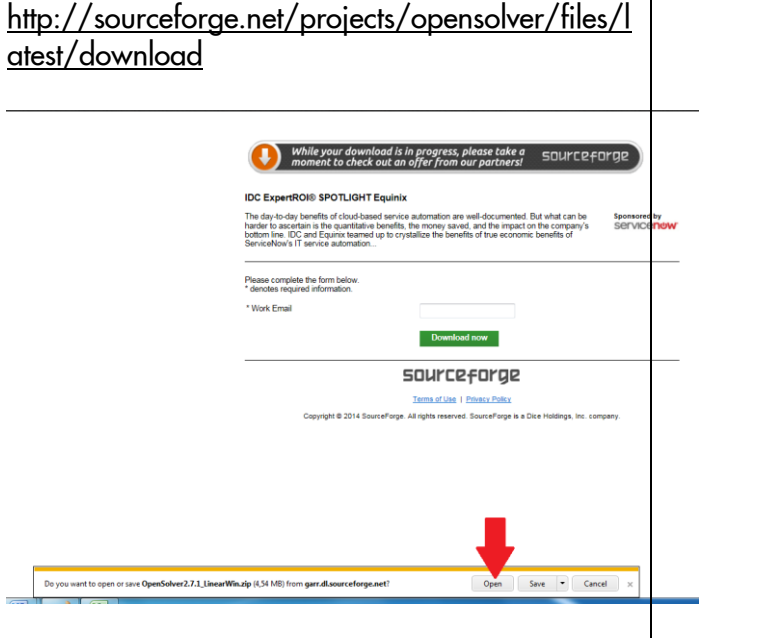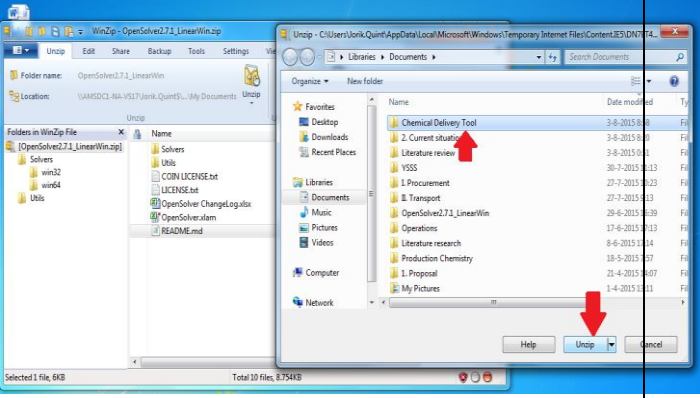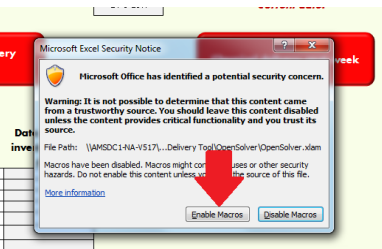
	o Unzip to..: Folder Chemical Delivery Tool My Documents → Chemical Delivery Tool o Press: Unzip OpenSolver will now be installed to your map "Chemical Delivery Tool"	
3.   Develop Sub Folders in Chemical Delivery Tool folder
3.1	Open Folder Chemical Delivery Tool Documents → My Documents → Chemical Delivery Tool o Save *Initial_PlanningTool_ChemicalDelivery* **To Folder**: Documents →Chemical Delivery Tool o Create new folder: Data o Create new folder: Planning Tool	\\AMSDC1-NA-**V517****Jorik.Quint**$\Cached\My Documents\Chemical Delivery Tool **File**: Initial_PlanningTool_ChemicalDelivery \\AMSDC1-NA-**V517**\\**Jorik.Quint**$\Cached\My Documents\Chemical Delivery Tool\Data \\AMSDC1-NA-**V517****Jorik.Quint**$\Cached\My Documents\Chemical Delivery Tool\Planning Tool
4.   Adjust VBA code in Excel to Personal Settings
4.1	Open File from "Chemical Delivery Tool" *Initial_PlanningTool_ChemicalDelivery* ▪ Open File from My Documents → Chemical Delivery Tool → OpenSolver: *OpenSolver.xlam* o Pop-up appears: Press Enable macros	\\AMSDC1-NA-V517**Jorik.Quint**$\Cached\My Documents\Chemical Delivery Tool \\AMSDC1-NA-V517\\**Jorik.Quint**$\Cached\My Documents\Chemical Delivery Tool\OpenSolver

	▪ Open VBA: o Press Alt+F11	See picture below	
	1&2 Open Module 1: o You can find Module 1 in left bar	See picture below	
	3&4 Adjust the Name Jorik.Quint to your name		

5.	Download Chemical Injection Volumes from Business Objects		

5.1	▪ Go to Business Objects
	
	▪ Sign in with your personal login code
	  o Go to: Documents
	  o Select: Folders
		https://sww-bi-ad.europe.shell.com:8443/BOE/BI	

87
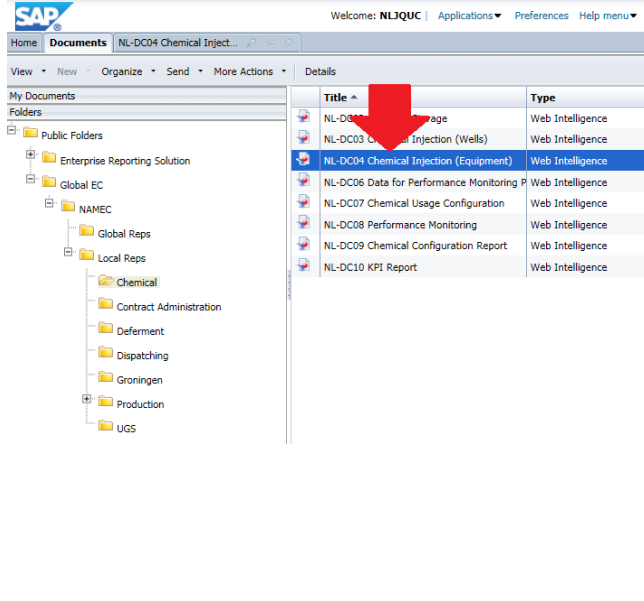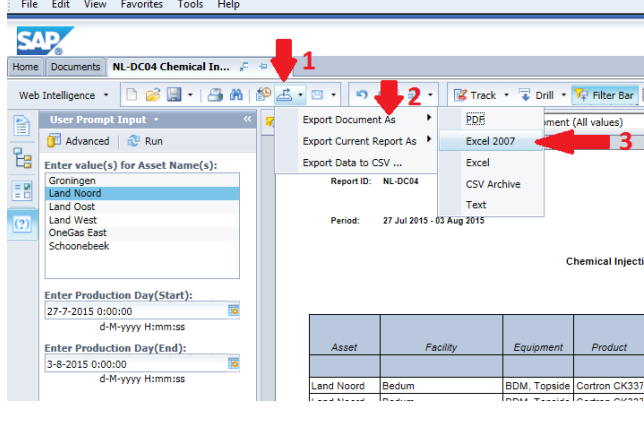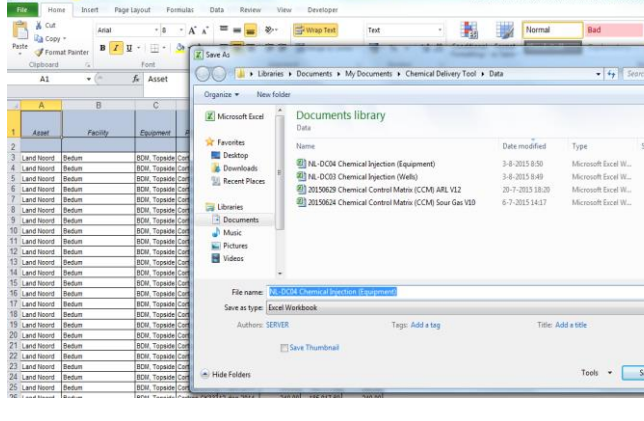
	▪ In Folders:
	  o Select Folder: Global EC
	  o Select Folder: NAMEC
	  o Select Folder: Local Reps
	  o Select Folder: Chemical
	  o Open: NL-DC03 Chemical Injection (Wells)	
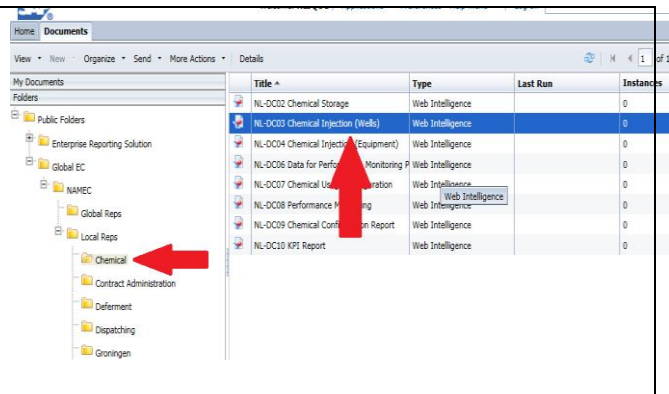
5.2	▪ Download Chemical injection volumes
	  o Select: Advanced
	  o Select:
	    - Land Noord
	    - Land Oost
	    - Schoonebeek
	  o Select by pressing the ">" button
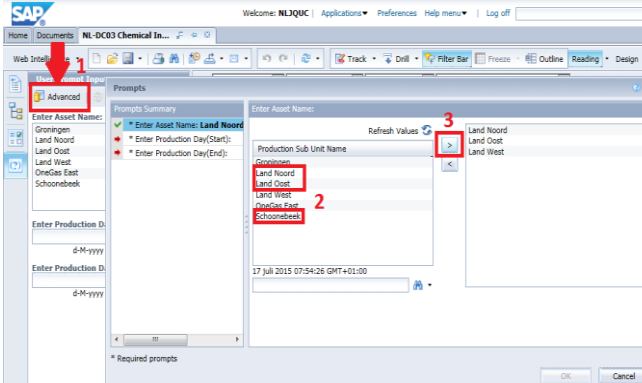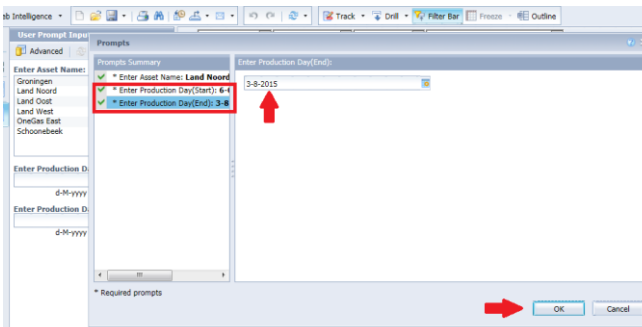	
	  o Select: Enter Production Day(Start)
	    - Insert a date (e.g. four weeks ago)
	  o Select: Enter Production Day(End)
	    - Insert current date
	  o Press OK
	
	Business Object will automatically download the injection volumes

5.3	Follow procedure **5.1 & 5.2**, now selecting a different file: "NL-DC04 Chemical Injection (Equipment)"	
	➔ Adjustment to step 5.1	
	o Open: NL-DC04 Chemical Injection (Equipment) *Instead of NL-DC03 Chemical Injection (Wells)*	
5.4	Export both documents to Excel For: NL-DC03 Chemical Injection (Wells): o Press the Export Button o Export Document As o Excel 2007 Follow this procedure for the file: NL-DC04 Chemical Injection (Equipment)	
5.5	Save the files in Folder: My Documents → Chemical Delivery Tool → Data o Save document as: NL-DC04 Chemical Injection (Equipment) o And save document as: NL-DC03 Chemical Injection (Wells)	

Appendix IX: Manual for running the Chemical Distribution Tool

This manual is developed to help you running the Chemical Distribution tool. In order to solve the Chemical Distribution tool, you should download the Chemical injection volumes, add recent distribution of Chemicals per injection point, and check (calculated) current inventory levels. For optimal performance of the tool, it is recommended to ask current inventory levels from Operations. The following steps are determined to run the Chemical Distribution tool:

Step	Description	Screenshots /details
0. Download Chemical injection volume of last four weeks		
0.1	▪ Go to Business Objects	https://sww-bi-ad.europe.shell.com:8443/BOE/BI

0.2	▪ Select two files:
	
	Home -> Last updated:
	
	  o NL-DC03 Chemical Injection (Wells)
	  +
	  o NL-DC04 Chemical Injection (Equipment)	

0.3	▪ Download Chemical injection volumes for both files:
	
	  o Select: Advanced
	  o Select:
	    - Land Noord
	    - Land Oost
	    - Schoonebeek
	  o Select by pressing the ">" button
	
	  o Select: Enter Production Day(Start)
	    - **Start date: 4 weeks prior to current date**
	  o Select: Enter Production Day(End)
	    - End date: **Current date**
	  o Press OK	

| 0.4 | ▪ Export both documents to Excel

For: NL-DC03 Chemical Injection (Wells):
  o Press the Export Button
  o Export Document As
  o Excel 2007
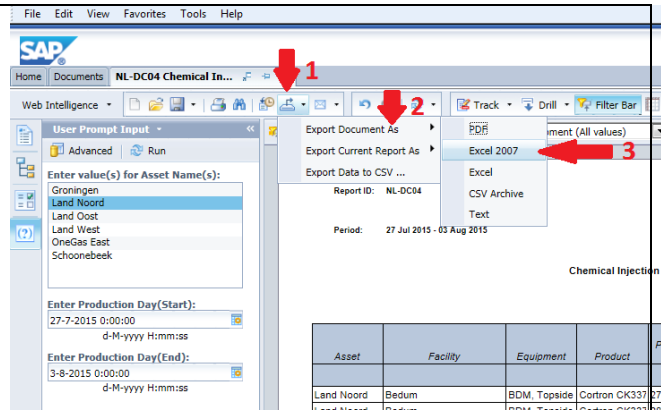
Follow this procedure for the file: NL-DC04 Chemical Injection (Equipment) | |
| 0.5 | ▪ Save the files in Folder:
My Documents → Chemical Delivery Tool → Data

  o Save document as:
    NL-DC04 Chemical Injection (Equipment)
  o And save document as:
    NL-DC03 Chemical Injection (Wells) | |
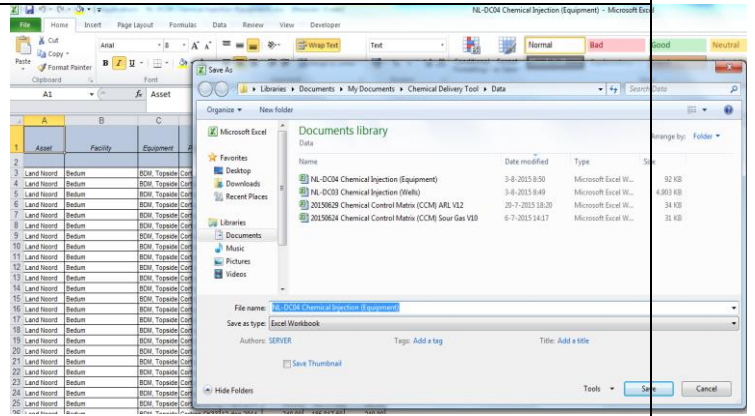
1. Open Initial_PlanningTool_ChemicalDelivery	

| 1.1 | ▪
▪ Go to: Documents → My Documents → Chemical Delivery Tool

▪ Open: Initial_PlanningTool_ChemicalDelivery.xlam | \\AMSDC1-NA-V517\Jorik.Quint$\Cached\My Documents\Chemical Delivery Tool\Initial_PlanningTool_ChemicalDelivery.xlam

>>>>Adjust Name to your Name<<<< |
| 1.2 | Worksheet: Dashboard opens

  o Following Dashboard pops up: | |

2.	Insert Chemical delivery data in the Table	
2.1	▪ Please add following dates to the dashboard: 　o Current date 　o Next delivery date 　o Last date the Planning tool has been updated (last time the Planning Tool has been solved) 　o Last date of (the weekly) Chemical Delivery trip	
2.2	▪ Insert the number of IBCs which are delivered per injection location, between current date and the last time the Planning tool has been updated (solved)	
2.3a	▪ Add the inventory levels per injection location from last update in the Planning Tool ▪ These inventory levels can be acquired from the last solved Planning Tool 　o Go to Worksheet: 'Planning' 　o Select column Y: Current inventory level	

2.2b	>>>>At least once a month<<<< ▪ Adjust inventory levels based on physical inspection of inventory levels. This information should be requested from Operations, **at least once a month**. ▪ If you receive inventory levels from Operations: Add the date of physical inspection next to the inventory levels. This is required for further calculations.	

3. Upload Chemical injection volumes in Planning Tool		
3.1	▪ Press the left button: o *Import Chemical injection volumes* Now, the chemical injection volumes extracted from Business Objects will be uploaded in the Planning tool	

4. Check Worksheet 'Horizon Planning'		
4.1	▪ Go to Worksheet: 'Horizon Planning' ▪ Check Table: Expected inventory level (Column $L$6:$P$66) If you see cells filled with a **RED** color, this means there is something wrong with the calculated current inventory levels.	

	▪ Please contact the Operator in charge for this injection point, to acquire his most recent chemical inventory level for the particular injection point. ▪ Manually adjust the inventory levels for the particular injection points for week 0 at worksheet 'Horizon Planning' (Column L).	 Adjust the inventory level in the red cell

5.	**Solve Chemical Delivery Tool**	
5.1	▪ Press button: 'Return to Dashboard' ▪ Press button: 'Solver Chemical Delivery Model'	

6.	**Develop schedule for coming Chemical Delivery**	
6.1	▪ Press button: 'Return to Dashboard'	

6.2	▪ Press button: 'Chemical delivery next week' ` ▪ Solution will automaticalle appear in Worksheet: 'LocationOutput'	

7.	Compare this 'optimal' schedule with orders from Operations	
7.1	▪ Compare the requests from Operations with the proposed planning from the Planning Tool ▪ Suggest to deliver the IBCs which are not ordered by Operations, but which are proposed by the Planning Tool ▪ Suggest to postpone delivery of requested IBCs which are requested by Operations, but not proposed by the Planning Tool	

Appendix X: Manual for adjusting the Chemical Distribution Tool

This manual is developed to help adjusting the Chemical Distribution Model. In case a new injection location is installed, it is important that you are able to add this location to the Chemical Distribution Model. Following manual guides you through all the required steps to add a new injection location to the Model. Adding a new location to this model requires a lot of effort and it would therefore be easier to replace an existing locations, which is no longer in production, with a new location. When you would like to add a new location to the Chemical Delivery Model, several formulas in Excel needs to be inserted, or updated. Please ask a graduate from the Logistics Department for support.

Step	Description	Screenshots /details
8. Add injection location to sheet 'Dashboard'		
0.1	▪ Open Initial_PlanningTool_ChemicalDelivery	
0.2	▪ Add the information about the new Injection Location to the Table: o Number of location o Name of the well o Name of the injection location o Name of the Skid o Chemical name	
9. Adjust Worksheet 'Planning'		
1.1	▪ Open Worksheet 'Planning'	

	▪ Fill in additional well information as already mentioned in previous step, see picture	

Fill in additional well information table:

	Asset	Facility	Equipment	Storage tank
4	Land Noord	Bedum	BDM, Topside V31	SKID12 (4m3)
5	Land Noord	Grijpskerk 1	GRK1, Waco to Delfzijl	V90
6	Land Noord	Westerveld	WTV, Wetgas transport line	T701 A+B (2.5 m3)
58	Land Oost	Gasselternijveen 1	GASSELTERNIJVEEN- 1	FRIS012; 3,5 m³
59	Land Oost	Dalen 9	Dalen- 9	1 m³
60	Land Oost	Dalen 9	Dalen- 9	1 m³
61	Land Oost	Hoogenweg 1	HOOGENWEG- 2	KISS008 (4m3)
62	Land Oost	Hardenberg 2	HARDENBERG- 2	FRIS018 (4m3)
63	Land Oost	Collendoornerveen 1	COLL'DOORNERVEEN- 1	4 m³
64	Land Oost	Den Velde 1	DEN VELDE- 1	DVD1-V-14 (3,5m3)
65	…	…	…	…

1.2

▪ Copy formula's from either row above, or from the first row of the Table

- o Copy Formulas from row abow when the Chemical injection volumes are received from data input 'NL-DC03'
- o Copy Formulas from the first row in the Table, when the Chemical injection volumes are received from data input 'NL-DC04'

Counter reading	Chemicals injected	Chemicals injected	Chemicals injected negative	Production Hours	Consumption per day	Last update physical inventory check	Last Update physical/BI
221378	2076	929	154			9/14/2015	9/20/2015
74686	804	333	62			9/14/2015	9/20/2015
29576	0	0	0			9/14/2015	9/7/2015
3450	129	52	51	First ROW 9		9/14/2015	9/21/2015
1879	219	77	23	292 OR 18		9/14/2015	9/21/2015
1031	140	62	23	292 Last ROW 12		9/14/2015	9/21/2015
6648	303	0	0	67		9/14/2015	9/21/2015
24028	12	0	0	114	2	9/14/2015	9/21/2015
11956	149	33	90	101	35	9/14/2015	9/21/2015
489	27	0	0	167	4	9/14/2015	9/21/2015
…	…	…	…	…	…	…	…

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+

Counter reading	Chemicals injected	Chemicals injected	Chemicals injected negative	Production Hours	Consumption per day	Last update physical inventory check	Last Update physical/BI
221378	2076	929	154			9/14/2015	9/20/2015
74686	804	333	62			9/14/2015	9/20/2015
29576	0	0	0			9/14/2015	9/7/2015
3450	129	52	51	334	9	9/14/2015	9/21/2015
1879	219	77	23	292	18	9/14/2015	9/21/2015
1031	140	62	23	292	12	9/14/2015	9/21/2015
6648	303	0	0	109	67	9/14/2015	9/21/2015
24028	12	0	0	114	2	9/14/2015	9/21/2015
11956	149	33	90	101	35	9/14/2015	9/21/2015
489	27	0	0	167	4	9/14/2015	9/21/2015
…	…	…	…	…	…	…	…

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1.3

▪ Add additional information
- o Chemical name
- o Storage capacity

Product	Average daily injection last week	Average daily injection	Max daily injection	Storage capacity [Ltr]
Cortron CK337C50	154,79	148,3	155,5	3700
CGO85011	55,49	57,5	62,7	3700
CGO85011		0,0	0,0	2300
Emulsotron X8336	7,428571429	8,6	10,0	3200
EC1144W	11,06108747	14,6	21,0	900
OS19	8,916015625	9,3	10,9	900
Cortron CK352	0	20,2	87,0	3700
Cortron CK352	0	0,8	10,9	3700
Cortron CK352	4,714285714	9,9	52,2	3700
Cortron CK352	0	0,0	6,9	3200
…		…		…

Chemical name   Storage capacity

		Copy Formula's from either row above, or from the first row in the Table (see step 1.2)	

10. Adjust sheet 'Horizon Planning'

2.1	• Open worksheet 'Distances' • Add address of the injection location after the last row • Add address of the injection location after the last column	
2.2	• Adjust VBA code to add the new location o Press Alt + F11 o Step 1: Open Module 2 o Scroll down until you see 'Sub CalculateDistances() o Step 2: Adjust j = 1 to 62 to: j = 1 to 63 o Step 3: Adjust i = 1 to 62 to: I = 1 to 63 o Step 4: Adjust i = 1 to 62 to: i = 1 to 63	

	▪ Step 5: Press Save button		
2.3	▪ Press button Calculate Duration in Worksheet to calculate al durations		

11. Adjust sheet 'Horizon Planning'

3.1	▪ Start with expending all the Tables with information from the new injection location
	
	Names of Tables:
	  o Consumption information
	  o Number of orders
	  o Auxiliary variable
	  o Travel durations
	  o Transport route week 1
	  o Transport route week 2
	  o Transport route week 3
	  o Transport route week 4
	  o Visited locations in week i
	  o Amount locations in week i
	  o Traversed locations in week i
	  o Number of visits week 1
	  o Number of visits week 2
	  o Number of visits week 3
	  o Number of visits week 4
	  o Auxiliary u(i) week 1
	  o Auxiliary u(i) week 2
	  o Auxiliary u(i) week 3
	  o Auxiliary u(i) week 4
	  o Auxiliary u(j) week 1
	  o Auxiliary u(j) week 2
	  o Auxiliary u(j) week 3
	  o Auxiliary u(j) week 4	

3.2	▪ Adjust formulas to calculate total durations with new locations	
3.3	▪ Open: OpenSolver.xlam ▪ Go to: Tab 'Data' in Excel	
	▪ Open Model in OpenSolver	
	▪ You now see the formulas used to by OpenSolver to calculate the durations	

- Press: Save Model
  - This will show all calculation fields within the Model.
  - You can now identify which fields are missing in the calculations -> Picture shows some of the calculation fields

- Open Model in OpenSolver once again

- Adjust the calculations in OpenSolver in order to include the new location in the requirements for running te model

- o Variable Cells
- o Constraints

Appendix XI: Chemical Distribution Model layout (Dashboard)

Chemical delivery planning for IBC transport
Chemical delivery planning tool for Land North, Ten Arlo and Sour Gas

20-8-2015

Next delivery date: 31-12-2014   *Current date:* 24-12-2014   *Last updated:* 17-12-2014

Last delivery date: 17-12-2014

[Import Chemical injection volumes]   [Solve Chemical Delivery application]   [Chemical delivery next week]

#	Facility	Equipment	Injection skid	Production Chemical	# of IBCs delivered	Inventory level	Date physical inventory level check
1	Bedum	BDM, Tapride V31	SKID12 (4m3)	Cartran CK337C50	3	2024	
2	Grijpskerk1	GRK1, Waca ta Delfzijl	V90	CG085011	0	2442	
3	Westerveld	WTV, Wetgar transport li	T701A+B (2.5 m3)	CG085011	0	1257	
4	Zevenhuizen1	ZVH1, Manifold	SKID13 (4m3)	CG085528	2	591	
5	Garzeltornijveen1	GSV1, Outlet_V-60	FRIS013; 3,5 m³	Gyptran SA3420	0	424	
6	Garzeltornijveen1	GSV1, Inlet_V-60	FRIS014; 3,5 m³	OS19	0	2072	
7	Schaanebeek313	SCH313, Injection in wat	Mather IBC; 1,5 m³	OS19	0	1255	
8	Schaanebeek313 Water	SCH313WD, Water inlet	Mather IBC; 1,5 m³	Bactran UCA495G	0	623	
9	Schaanebeek313 Water	SCH313WD, Water Inlet	Mather IBC; 1,5 m³	INH3-6156 (WLaaq)	0	407	
10	Schaanebeek313 Water	SCH313WD, Water inlet	Mather IBC; 1,5 m³	OS19	0	880	
11	Schaanebeek313 Water	SCH313WD, Water Outle	Mather IBC; 1,5 m³	INH3-6157 (WZuur)	1	461	
12	Schaanebeek313 Water	SCH313WD, Water outle	Mather IBC; 1,5 m³	OS19	0	1216	
13	Schaanebeek313 Water	SCH313WD, T-17-P28C	Mather IBC; 1,5 m³	FX-2443	0	837	
14	Callandaarnorveen1	CLDV1	4 m³	DFO85667	0	2709	
15	Assen1	ASSEN-1	SKID15 (4m3)	CG085528	0	2392	
16	De Tibben1	DE TIBBEN-1	SKID021	CG085011	0	2748	
17	De Tibben1	DE TIBBEN-2	SKID047	Cartran CK337C50	0	2027	
18	De Tibben1	DE TIBBEN-3	SKID048	Cartran CK337C50	0	2275	
19	Faan	FAAN-1	KISS005 (4m3)	CG085011	0	2715	
20	Faan	FAAN-2	SKID005 (4m3)	CG085011	0	2225	
21	Lauwerzijl	LAUWERZIJL-1	FRISS024 (3,5m3)	Faametran V-505	0	2138	
22	Leens	LEENS-1 - Well Hole	FRISS005 (3.5m3)	Faametran V-505	0	-61320	
23	Marum1	MARUM-1	Skid031 (4m3)	CG085528	0	3025	
24	Marum1	MARUM-1	Skid029 (4m3)	CG085528	2	2048	
25	Marum1	MARUM-2	Skid002 (4m3)	CG085528	0	2130	
26	Marum1	MARUM-2	Skid003 (4m3)	CG085528	0	2046	
27	Munnekezijl1	MUNNEKEZIJL-3	V-65-3 (1m3)	DFO85667	0	841	
28	Munnekezijl1	MUNNEKEZIJL-3 - Well H	IBC (3m3)	Faametran V-505	0	1367	
29	Norg3	NORG-6	SKID54 (4m3)	CG085011	0	645	
30	Norg3	NORG-6	SKID70 (4m3)	Methanal-Ltr	0	2044	
31	Opende Oart1	OPENDE-OOST-1	rkid001	CG085528	1	2911	
32	Sebaldeburen1	SEBALDEBUREN-1	FRISS006 (3.5m3)	Trifoam 820 black	0	2411	
33	Surhuisterveen1	SURHUISTERVEEN-1	SKID003 (4m3)	CG085528	0	2806	
34	Tietjerksteradeel700	TIETJERKSTERADEEL-7	SKID28 (4m3)	CG085528	0	3209	
35	Vries1	VRIES-103	SKID004 (4m3)	CG085528	0	3812	
36	Vries1	VRIES-103	SKID009 (4m3)	Methanal-Ltr	0	2646	
37	Vries4	VRIES-402	DFRIS005 (3.5m3)	DFO85667	0	1445	
38	Vries4	VRIES-402	FRISS017 (3.5m3)	Faametran V-505	0	2278	
39	Witten1	WITTEN-2	FRISS020	Trifoam 820 black	0	545	
40	Witten1	WITTEN-2 - Well Hole	SKID008 (4m3)	CG085011	0	811	
41	Witten1	WITTEN-3	SKID24 (4m3)	CG085011	0	2960	

Appendix XI: Chemical Distribution Model solution (Automatic calculations)

Chemical Injection from Business Objects
Chemical injection from last four weeks per injection location

Return to Dashboard

Facility		Equipment	bulk / ibc	Storage tank	Counter reading	Chemicals injecte	Chemicals injecte	Chemicals injected negativ	Last update physical invento	Last Update physicalE	Product	Average daily injection last week	Average daily injectic	Max daily injectic	Storage capaci [Ltr]	Inventory level last chec [Ltr]	Safety inventory level [Ltr]	Max recomm. Dose rate [Ltr/Day]	Chemical deliver this we [Ltr]	Current inventory level [Ltr]
Bedum	BDM	BDM, Topside V31	IBC	SKID12 (4m3)	187873	6940	1670	240	17-12-2014	24-12-2014	Cortron CK337C50	238,57	239,3	250,0	3700	2024	1875	163	3000	3354
Grijpskerk 1	GRK	GRK1, Waco to Delfzijl	IBC	V90	62236	1602	183	33	17-12-2014	24-12-2014	CGO85011	27,06	55,3	166,4	3700	2442	587	0	0	2253
Westerveld	WRV	WTV, Wetgas transport line	IBC	T701 A+B (2.5 m3)	25644	534	115	16	17-12-2014	24-12-2014	CGO85011	16,39	18,4	21,5	2300	1257	329	0	0	1142
Zevenhuizen 1	ZVH	ZVH1, Manifold	IBC	SKID13 (4m3)	2915	1516	308	20	17-12-2014	24-12-2014	CGO85528	44,00	52,3	83,0	3700	591	566	0	2000	2283
Gasselternijveen 1	GSV1	GSV1, Outlet_V-60	ibc	FRIS013; 3,5 m³	371	62	15	2	17-12-2014	24-12-2014	Gyptron SA3420	2,14	2,1	7,0	3200	424	215	20	0	409
Gasselternijveen 1	GSV1	GSV1, Inlet_V-60	ibc	FRIS014; 3,5 m³	4167	201	48	8	17-12-2014	24-12-2014	OS19	6,86	6,9	20,0	3200	2072	249	12	0	2024
Schoonebeek 313	S313	SCH313, Injection in water retent	IBC	Mother IBC; 1,5 m³	1938	111	26	5	17-12-2014	24-12-2014	OS19	3,78	3,8	5,5	1300	1255	227	5	0	1229
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, Water inlet V-19-1- B	IBC	Mother IBC; 1,5 m³	463	70	50	5	17-12-2014	24-12-2014	Bactron UCA495G	7,12	2,4	25,4	1300	623	217	12	0	573
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, Water inlet V-19-1- p	IBC	Mother IBC; 1,5 m³	2505	316	140	25	17-12-2014	24-12-2014	INH 3-6156 (WLoog	20,07	10,9	56,4	1300	407	276	5	0	267
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, Water inlet to T-18	IBC	Mother IBC; 1,5 m³	2077	433	96	24	17-12-2014	24-12-2014	OS19	13,71	14,9	31,0	1300	880	305	8,4	0	784
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, Water Outlet V-17 pi	IBC	Mother IBC; 1,5 m³	2531	490	215	30	17-12-2014	24-12-2014	INH 3-6157 (WZuur)	30,72	16,6	99,8	1300	461	316	1	1000	1246
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, Water outlet V-19-1-	IBC	Mother IBC; 1,5 m³	1934	193	96	16	17-12-2014	24-12-2014	OS19	13,69	6,9	43,2	1300	1216	248	8,4	0	1120
Schoonebeek 313 Water Disposal	S313-W	SCH313WD, T-17-P28C	IBC	Mother IBC; 1,5 m³	627	156	26	7	17-12-2014	24-12-2014	Gyptron SA3420	3,69	5,4	12,0	1300	807	238	13	0	811
Collendoornerveen 1	CLDV	CLDV1	IBC	4 m³	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	2709	200	36	0	2709
Assen 1	ASN1	ASSEN-1	IBC	SKID15 (4m3)	116510	0	0	0	17-12-2014	24-12-2014	CGO85011	0	0,0	0,0	3700	2392	200	56,1	0	2392
De Tibben 1	TBN	DE TIBBEN-1	IBC	SKID021	42888	2622	642	70	17-12-2014	24-12-2014	CGO85011	91,71428571	90,4	125,0	3700	2748	833	37,5	0	2106
De Tibben 1	TBN	DE TIBBEN-2	IBC	SKID047	12574	1693	404	62	17-12-2014	24-12-2014	Cortron CK337C50	57,71428571	58,4	78,0	3700	2027	609	20	0	1623
De Tibben 1	TBN	DE TIBBEN-3	IBC	SKID048	18554	1574	373	53	17-12-2014	24-12-2014	Cortron CK337C50	53,28571429	54,3	70,0	3700	2275	580	60	0	1902
Faan	FAN	FAAN-1	IBC	KISS005 (4m3)	122167	2386	548	33	17-12-2014	24-12-2014	CGO85011	78,28571429	82,3	112,0	3700	2715	776	88	0	2167
Faan	FAN	FAAN-2	IBC	SKID005 (4m3)	0	0	0	0	17-12-2014	24-12-2014			0,0	0,0	3700	2225	200	57,5	0	2225
Lauwerzijl	LWZ	LAUWERZIJL-1	IBC	FRIS024 (3,5m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	2138	200	0	0	2138
Leens	LNS	LEENS-1- Well Hole	IBC	FRIS005 (3.5 m3)	957593	17694	4249	610	17-12-2014	24-12-2014	Trifoam 820 block	607,0089286	610,1	639,6	3200	-61320	4471	40	0	-65569
Marum 1	MAR1	MARUM-1	IBC	Skid031 (4m3)	34620	3393	755	139	17-12-2014	24-12-2014	CGO85528	107,8571429	137,7	184,0	3700	3025	1164	35	0	2270
Marum 1	MAR1	MARUM-1	IBC	Skid029 (4m3)	34620	3393	755	139	17-12-2014	24-12-2014	CGO85528	107,8571429	137,7	184,0	3700	2048	1164	35	2000	3293
Marum 1	MAR1	MARUM-2	IBC	Skid002 (4m3)	50401	3515	713	118	17-12-2014	24-12-2014	CGO85528	101,8571429	121,2	152,0	3700	2130	1048	57,5	0	1417
Marum 1	MAR1	MARUM-2	IBC	Skid003 (4m3)	50401	3515	713	118	17-12-2014	24-12-2014	CGO85528	101,8571429	121,2	152,0	3700	2046	1048	57,5	0	1333
Munnekezijl 1	MKZ1	MUNNEKEZIJL-3	IBC	V-65-3 (1m3)	0	0	0	0	17-12-2014	24-12-2014	DFO85667	0	0,0	0,0	900	841	200	10	0	841
Munnekezijl 1	MKZ1	MUNNEKEZIJL- 3 - Well Hole	IBC	IBC (3m3)	53425	0	0	0	17-12-2014	24-12-2014	Trifoam 820 block	0	0,0	0,0	2800	1367	200	60	0	1367
Norg 3	NOR3	NORG-6	IBC	SKID54 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	645	200	21,25	0	645
Norg 3	NOR3	NORG-6	IBC	SKID70 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	2044	200	0	0	2044
Opende Oost 1	OPO1	OPENDE-OOST-1	IBC	skid001	70576	2060	403	80	17-12-2014	24-12-2014	CGO85528	58,42857143	71,0	122,0	3700	2911	697	0	1000	3502
Sebaldeburen 1	SEB1	SEBALDEBUREN-1	IBC	FRIS006 (3.5m3)	14153	0	0	0	17-12-2014	24-12-2014	Sebaldburen 1	0	0,0	0,0	3200	2411	200	40	0	2411
Surhuisterveen 1	SHV1	SURHUISTERVEEN-1	IBC	SKID003 (4m3)	14851	1500	303	50	17-12-2014	24-12-2014	CGO85528	43,28571429	51,7	71,0	3700	2806	562	25	0	2503
Tietjerksteradeel 700	TID7	TIETJERKSTERADEEL-702	IBC	SKID28 (4m3)	90554	1579	144	50	17-12-2014	24-12-2014	CGO85528	20,57142857	54,4	89,0	3700	3209	581	22,5	0	3065
Vries 1	VRS1	VRIES-103	IBC	SKID004 (4m3)	81341	310	1	0	17-12-2014	24-12-2014	CGO85528	0,142857143	31,4	151,0	3700	3812	420	0	0	3811
Vries 1	VRS1	VRIES-103	IBC	SKID009 (4m3)	101943	0	0	0	17-12-2014	24-12-2014	Methanol-Ltr	0	0,0	0,0	3700	2646	200	0	0	2646
Vries 4	VRS4	VRIES-402	IBC	DFRIS005 (3.5m3)	10633	1110	237	105	17-12-2014	24-12-2014	Cortron CK337C50	42,44796317	38,3	56,0	3200	1445	468	8	0	1148
Vries 4	VRS4	VRIES-402	IBC	FRIS017 (3.5m3)	6367	179	47	105	17-12-2014	24-12-2014	DFO85667	6,646902902	6,2	6,7	3200	2278	243	50	0	2232
Witten 1	WIT1	WITTEN-2	IBC	FRIS020	5232	0	0	0	17-12-2014	24-12-2014	Trifoam 820 block	0	0,0	0,0	3200	545	200	0	0	545
Witten 1	WIT1	WITTEN- 2 - Well Hole	IBC	SKID008 (4m3)	209490	0	0	0	17-12-2014	24-12-2014	CGO85011	0	0,0	0,0	3700	811	200	92,5	0	811
Witten 1	WIT1	WITTEN-3	IBC	SKID24 (4m3)	238472	2523	633	704	17-12-2014	24-12-2014	CGO85011	98,28571429	87,3	110,0	3700	2960	811	28,75	0	2272
Witten 1	WIT1	WITTEN-3	IBC	SKID25 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	3362	200	30	0	3362
Witten 1	WIT1	WITTEN-3	IBC	SKID26 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	3326	200	0	0	3326
Witten 1	WIT1	WITTEN-5	ibc	SKID045 (4 m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	875	200	36	0	875
Witten 1	WIT1	WITTEN-5	IBC	SKID073 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	1195	200	0	0	1195
Witten 1	WIT1	WITTEN-5	IBC	SKID076 (4m3)	0	0	0	0	17-12-2014	0-1-1900			0,0	0,0	3700	2247	200	0	0	2247

Appendix XI: Chemical Distribution Model solution (Model)

Chemical Delivery Solver

Return to Dashboard

Information available in SAP systems which can be extracted on weekly basis

Asset | Facility | Equipment | Average daily injection | Capacity (Cj) | Expected Consumption (Vij): Week 1, Week 2, Week 3, Week 4 | Safety inventory level (Sj) | Expected inventory level (Iij) | Inventory - Safety stock

Number of orders which could be ordered, given storage capacity per Chemical Injection point

Facility | Max. orders (Mij) | Orders placed (Oj) | Auxiliary variable (ui)

Appendix XI: Chemical Distribution Model solution (Final outcome)

Planning IBC transport for coming week

Return to Dashboard

Location	Facility	Injection location	Skid	Production Chemical	Number of IBCs
1	Gasselternijveen 1	GASSELTERNIJVEEN- 1	FRIS012; 3,5 m3	Emulsotron X8336	1
2	Hoogenweg 1	HOOGENWEG- 2	KISS008 (4m3)	Cortron CK352	2
3	Hardenberg 2	HARDENBERG- 2	FRIS018 (4m3)	Foamatron V-505	1
4	Schoonebeek 313	SCH313WD, Water Inlet	Mother IBC; 1,5 m3	INH 3-6156 (WLoog)	1
5	Marum 1	MARUM-1	Skid029 (4m3)	CGO85528	1
6	Marum 1	MARUM-2	Skid003 (4m3)	CGO85528	3
7	Marum 1	MARUM-1	Skid031 (4m3)	CGO85528	2
8	Marum 1	MARUM-2	Skid002 (4m3)	CGO85528	2
9	Faan	FAAN-1	KISS005 (4m3)	CGO85011	1
10	De Tibben 1	DE TIBBEN-1	SKID021	CGO85011	2
11	De Tibben 1	DE TIBBEN-3	SKID048	Cortron CK337C50	1
12	De Tibben 1	DE TIBBEN-2	SKID047	Cortron CK337C50	1
13	Bedum	BDM, Topside V31	SKID12 (4m3)	Cortron CK337C50	2

Duration	
Loading hours	4
Travelling hours	5,098301
Unloading hours	5
Total	**14,098301**

Total number of IBCs   **20**