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MASTER

Optimizing the aggregate inventory levels when commodity prices fluctuate seasonal

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Optimizing the aggregate inventory levels when commodity prices fluctuate seasonal

By

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In partial fulfilment of the requirements for the degree of

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in Operations Management and Logistics

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Abstract
In this master thesis project the aggregate inventory planning is optimized when prices are seasonal. In the first step of the thesis the products which can be used for optimizing the seasonal fluctuations of the base chemical are identified. For those products an LP model is developed which optimizes the inventory levels according to the price seasonality.
Management summary
The economic downturn following the financial crisis increased the pressure on profits of chemical producers. To remain competitive in these difficult economic times, companies run programs to decrease their costs. A big part of the costs of a chemical producer are the supply chain costs, which can account for as much as 80% of the total costs of a chemical producer. A number of enhancements have resulted in less volatile earnings and strengthened the financial position of The Chemical Company. To keep the process of generating higher value by operating and capital efficiency going, the company tries to reduce input.

In this research the input costs are being optimized to find the best time to produce or procure products. The price of the chemical investigated in this research, Chemical X, fluctuates seasonally. This means that in the last years, the price went up in quarter 1 and later on in the year the price went down. Figure 1 shows the average month-to-month price change of the last 15 years. A positive value for month 1 means the price is expected to go up from December to January. Figure 1 shows that the price is expected to go up in the first quarter of the year. In quarter 2 and beginning of quarter 3 the average price is expected to go down. However the upper limit is positive, except month 5, which means there is also a fair chance the price goes up in second and third quarter.

![Month to month change](image)

In this research therefore the inventory levels are calculate which will optimize the production and procurement of products for Chemical X and it derivatives. The derivatives are products which have Chemical X as their main ingredient.

Research design
In the thesis the following research question and sub-questions are stated:

What are the optimal inventory levels for a chemical product and its derivatives in a divergent, multi-echelon supply chain with seasonal prices?

This is solved by answering the following sub questions:
- How do chemical X and its derivatives flow through The Chemical Company?
- What are the optimal inventory levels when the price is seasonal and the price takes on its predicted value?
- What are the optimal inventory levels when the price is seasonal and the price is assumed to be stochastic?

Results
Currently it is not known where the all derivatives of chemical X are used in the company and how the flow. Every business unit knows its customers (internal and external), but the flow further downstream is not known by that business. To decide which derivatives are useful for hedging price seasonality of Chemical X, all possible derivatives are modeled in a flowchart. This flowchart can be found in appendix A.

5 products are chosen have potential when optimizing the inventory according to the price seasonality of chemical X. This means the products will have a significant impact on the total costs related to the raw material costs for chemical X. These products are Chemical X, Product A, Product D, Product F, and Product G. These products can be used to optimize the inventory according to the price seasonality of chemical X. However, the highest capital investment return (CIR) comes from Chemical X itself.

\[
CIR = \frac{\text{Change operating income}}{\text{Extra working capital} (t = 3)}
\]

The second best choice is Product A and third choice is product F. Product D and Product G have a lower return. Table 1 shows the forecasted capital investment return and the return that would have been made in the last 3 years for Q4-Q1.

<table>
<thead>
<tr>
<th>Year</th>
<th>CIR</th>
<th>Cost savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>20,7%</td>
<td>2,0%</td>
</tr>
<tr>
<td>2010-2011</td>
<td>18,6%</td>
<td>1,9%</td>
</tr>
<tr>
<td>2011-2012</td>
<td>25,2%</td>
<td>3,2%</td>
</tr>
<tr>
<td>2012-2013</td>
<td>7,0%</td>
<td>0,8%</td>
</tr>
</tbody>
</table>

Table 1: CIR and costs savings Q4-Q1

The best quarter to hedge for is quarter 1. Inventory should be built in quarter 4 so the inventory can be used in quarter 1. The best month to buy products, according to the price is November. When the desired amount of stock cannot be built in November, it is optimal to built stock in December. If in those 2 months still not the desired amount of stock can be built, extra products can be produced or bought in October. With production and inventory data from 2013 The Chemical Company is predicted to save 2% of its total costs.
The chemical industry is capital intensive and therefore the available capital is limited. Figure 2 shows that if less capital is available, the return on this capital will be higher. However, the total savings are higher when more capital is available.

Overall building stock in quarter 4 can add value to The Chemical Company. Chemical X, product A and product F will give the highest return, where Chemical X is expected to give the highest return and product F the lowest of the 3 products. If the amount of capital which is invested is higher, the return on this capital will be lower, but the overall savings will be higher.
Acknowledgement

In this report the results of my master thesis project of the master program Operations Management and Logistics (OML) at the Eindhoven University of Technology are presented. I conducted this research at a chemical producer in the Netherlands. With this completion of this project, the end to my life as a student is here. Therefore I would like to thank the people who supported me during this project and the rest of my study.

First I would like to thank my mentor, and first supervisor of the TU/e, Arun Chockalingam. Your guidance throughout the project, the new insights you gave me when I encountered problems and always finding some time in your agenda when I needed it is much appreciated. I would also like to thank my second supervisor from the university, Matthew Reindorp, for his useful feedback and opinion.

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Hans Amperse

Eindhoven, December 2013
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1. **Introduction**

The aim of this project is to investigate how the procurement, production and storage of products can be optimized when prices fluctuate seasonally. This is done for a chemical product, called chemical X, and products which have chemical X as their main ingredient, called derivatives of chemical X. The price of chemical X fluctuates seasonal and because of the seasonal price fluctuations of chemical X, the prices of products which have chemical X as their main ingredient also fluctuate seasonally. In this thesis the procurement, production and storage will be optimized for Chemical X and its most important derivatives. The derivatives that are most suitable for optimizing the inventory of chemical X molecules is are not known yet and need to be determined first. This thesis is executed at the supply chain department of a big chemical producer.

1.1. **Problem statement**

The economic downturn following the financial crisis increased the pressure on the profits of chemical producers. The chemical production in the European Union decreased by 11.8% in 2009 compared with 2008. In the past two years the production showed some recovery, but even with strong growth rates after 2009, it is still below the pre-crisis level (Cefic, 2012). To remain competitive in these difficult economic times, companies run programs to decrease their costs. A big part of the costs of a chemical producer are the supply chain costs, which can account for as much as 80% of the total costs of chemical manufacturer. Reducing the supply chain costs by 10 percent can bring a 40-50% improvement in before tax profits (Gibson, 1998).

Prices of chemical commodities have shown to be very volatile. These fluctuations are not constant over time. They have been especially high during the last decade(s). Customers may speculate and/or anticipate on the price in the future and adjust their target inventory levels to those prices (Pindyck, 2004). The chemical producer investigated in this research produces, buys, and sells chemical X. The amount of chemical X needed for downstream production and sales is greater than the amount produced in their own plants; hence they are a net buyer of chemical X. The company wants to explore what will be gained by adjusting the inventory targets to the seasonal price fluctuations of chemical X.

A number of enhancements have resulted in less volatile earnings and strengthened the financial position of The Chemical Company. To keep the process of generating higher value by operating and capital efficiency going, three key themes are initiated: reducing the input costs for processes, improving supply reliability and changing the way of working. Those themes need to enable more efficient ways of managing cash, costs and working capital. All of this needs to result in an increased cash flow.

A part of this plan is to lower the capital costs by optimizing the inventory utilization. By the end of 2013 the working capital coming from inventory needs to be reduced by 12%, compared to the level at the end of 2012. To reach this goal, every business unit received a target specifying the amount by which the inventory needs to be reduced. Those inventory targets are set for the end of the year. However, due to the seasonality, prices of chemical X are assumed to go up in the first quarter. Therefore the low inventory target does not correspond with the goal of managing costs and cash efficiently, since it can be beneficial to already buy (cheaper) in quarter 4 and store it. This will increase the working capital at the end of the year. However, it will also increase the cash flow and
reduce the input costs. For this research the focus will be on optimizing the inventory in the Europe, Middle East and Africa (EMEA) region according to price seasonality of chemical X.

Fluctuating prices can influence the competitiveness of the company. Hence, raw price volatility and increases have to be considered in sales and supply planning of commodity products, to ensure profitability of the business (Gaur et al., 2007). When a company has products on stock and the price decreases, the value of its inventory goes down and the company loses money. It would have been favorable to buy the products which are now on stock later, because they can be bought be at a cheaper price and, on top of that, there are no inventory costs. Likewise, when prices increase more than the inventory costs for that period, it is favorable to store more. It is cheaper to buy now and store it, compared to buying the products at a higher price in the future. However, the extra products on stock will give higher holding costs and increase the working capital coming from inventory. Therefore, an optimum between the extra holding costs, extra money needed and the increase in price needs to be found.

When trying to find this optimum, the variability of prices needs to be taken into account. Predicting commodity prices in the future is a tricky business and, therefore, not always accurate. Optimizing the inventory without taking price variance into account can only achieve 80% of the value of the optimal policy which takes uncertainty into account (Secomandi, 2010). To take full advantage and lower the risk of price fluctuations; the optimal desired inventory levels set in this thesis needs to take the variable prices of raw materials and products into account.

Summarized, the problem statement is defined as:

| Enabling The Chemical Company to achieve the company wide inventory costs reduction plan, by optimizing the inventory of chemical X and its derivatives while keeping in mind hedging decisions to maximize the value and minimize risks. |

1.2. Thesis outline
In Chapter 2, a general description of the chemical industry, the fluctuations of commodity prices, and the current situation at The Chemical Company will be described. This will lead to the research questions and the scope of the project in Chapter 3. In Chapter 4, the flow of chemical X will be mapped and it will be determined which derivatives are valuable to take into account when optimizing according to price fluctuations of chemical X. In Chapter 5, the procurement, production and storage will be optimized in a static environment. In chapter 6 a sensitivity analysis for the static model is done. The price becomes a stochastic variable in the optimization in chapter 7. Chapter 8 completes this with the conclusions and recommendations.
2. Chemical commodity industry

The chemical industry is one of the key global industries with global sales netting € 2744 billion in 2011 (Cefic, 2012). Figure 3: Overview chemical industry gives a simplified overview the different stages of the chemical industry. The chemical industry can be divided up in three wide ranges of products: base chemicals, specialty chemicals and consumer chemicals. Base chemicals are used as building blocks for specialty and consumer chemicals.

The products considered in this thesis are base chemicals. Base chemicals include petrochemicals, petrochemical derivatives, and basic inorganics. Inorganics are products which are not based on oil, coal or gas. Base chemicals are relatively simple to produce, as well as generic between producers. They are produced in large volumes, and are sold within the chemicals industry itself or to other industries to be further used in other products. In 2011, base chemicals represented 62.4 % of total EU chemicals sales (Cefic, 2012).

Base chemicals are commodities. Commodities are mass products produced and sold in high volumes with standardized quality and few variants. Chemical commodities are usually substitutable with
products from competing chemical companies. Therefore this is a competitive market, with low profit margins. Price is one of the key buying criteria for a customer (Kannegiesser et al., 2009). Sales prices for chemical commodities are volatile and can change regularly based on negotiations between the company and its customers. However, due to the highly competitive market an individual base chemical producer has very little pricing power. Some chemical commodities are also traded on the spot market.

The prices of goods produced by the chemical commodity industry have shown great volatility over time. The prices have shown to be very volatile compared to other industries and the extent of this volatility is not constant over time. It has been especially high during last decades, see figure 4. For customers, this may also include speculation and anticipation by adjusting the desired inventory levels based on their expectations of future price. However, chemical producers can also anticipate on these fluctuations. The raw materials they buy are also affected this volatility. Making good use of the increases and decreases in prices, businesses can ensure their profitability.

To make good use of these price fluctuations, companies in the chemical commodity industry need to not only take supply and demand into account in their planning, but they also need to adjust their planning to the fluctuating prices. The common assumption of constant purchase costs in planning is valid if the purchasing costs from one period to the next change less than the holding cost per period (Ferguson et al., 2006). However, because of the fluctuating commodity prices (see Figure 4) this assumption is not always valid for base chemicals.

Figure 4 shows the historical prices for three petrochemicals. The petrochemicals have the same products as raw material and therefore fluctuate similarly. Over the past 25 years the prices of these three chemicals have shown big fluctuations. With the small margins on base chemicals, these fluctuations can threaten the continuity of the company when it does not anticipate these fluctuations.
2.1. Price fluctuations of chemical X

Figure 4 shows the price fluctuations of three base chemicals between 1986 and 2011. In this chapter, a more in depth look will be taken at the price fluctuations of chemical X. Where Figure 4 provides good insight in the trend over several years, the managers at The Chemical Company had a feeling that the prices of chemical X fluctuate seasonally in every year itself.

Figure 5 shows the month-to-month price change of chemical X in Europe. The figure has an average, high and a low. The high and low lines, respectively, make up the upper and lower limits of the one sigma confidence interval (CI). It is assumed that the price changes follow a normal distribution, which means that one sigma confidence level is the 68% confidence interval. Price data of the last 15 years is used for the statistical analysis. Outliers due to external factors, like the financial crisis, are deleted in the analysis. In Figure 5, the 1 on the x-axis represents the change from December to January, 4 is the change from March to April, etc.

The month to month price change of chemical X is positive in the first quarter of the year for all the three lines. In the second and third quarter the average price change is negative, while the upper limit of the 68% confidence level is positive. This means there is still a reasonable chance of the price going up. The distance between the upper and lower limit increase in the third quarter, which means the seasonal trend is not the same over years. In some years the price went up, where in some years the price went down.

Most companies in the chemical business make the aggregate production plan one quarter in advance. In the fourth quarter, they make the planning of the first quarter of the next year. Therefore, it is useful to know how much the price will change in 3 months. Figure 6 shows the price change in 3 months. The 1 on the x-axis
represents the price change between October and January, the 4 stands for the price change between January and April, etc. The 3 month price change also shows that the price is going up in the first quarter of the year. Both the upper confidence and lower confidence interval are positive. The rest of the year the average price decreases, but the upper bound of the confidence interval shows increasing prices, while the lower bound shows decreasing prices. The distance between the upper and lower bound is larger in the second and third quarter, which implies greater uncertainty in the behavior of the price. In the last 15 years the price has shown different kinds of behavior in the second and third quarter of the year. In the fourth quarter the price is relatively stable. The average price change is about 0 and the upper and lower limit of the 68% confidence level are close to 0.

2.2. Current situation

Decisions concerning the inventory of chemical X and its derivatives are currently made by each business for their own products. Upstream business units get demand forecasts directly from the downstream businesses they supply. Therefore they can adjust their inventory on information of the business directly downstream, but they have no information from downstream businesses which are not directly connected to them. A chemical producer faces a lot of stages before the end customer is reached and, therefore, upstream businesses will react slower to actions of customers. In addition to this, the businesses do not evaluate over multiple businesses to determine where it is most favorable to keep inventory. When chemical X is held in its original form the value of the stock is lower than when it is held as a derivative product. However, storing products upstream makes the lead time longer and the storage capacity of chemical X is limited. To bring the inventory costs down it would be favorable to store them in earlier steps of the chemical X supply chain, but sufficient inventory in downstream stages is needed to be able to absorb deviations in demand.

The amount of inventory which businesses should have on stock is by an end quarter inventory target. The target at the end of the year is the most important one. The inventory targets at the end of quarter 1, 2 and 3 are set to reach the fourth quarter inventory target. To clean up their balance sheet at the end of the year, when the financial report is made, the fourth quarter inventory target is set very low. In January, inventory is built up again to make sure a certain service level can be maintained. With prices expected to increase in the first quarter of the year it might be beneficial to set the inventory target not too low.

Adjusting the inventory to price fluctuations is now mostly done by managers of the businesses. Responsible managers rely on their instinct when it comes to making decisions to increase or decrease inventory. Making decisions relying on instinct is risky and does not correspond with the goal of minimizing risk and maximizing value. Moreover, managers are limited in the amount of freedom they have for adjusting their targets.
3. Research objectives

3.1. Research questions

In order to find a solution for the problem statement, a research question is formulated. The research question is divided up in three sub questions to research question. The research question which will be answered in this research is:

1. **What are the optimal inventory levels for a chemical product and it derivatives in a divergent, multi-echelon supply chain with seasonal prices?**

   The goal of the project is to calculate the optimal inventory levels when they are adjusted to the expected price in the future. According to a study done at The Chemical Company, the price of chemical X is higher in some periods of the year. Adjusting the inventory levels to the seasonality of the price should reduce the costs for raw materials.

   To answer the above question in an orderly manner, it is divided into the following 3 sub questions.

   1.1 **How do chemical X and its derivatives flow through The Chemical Company?**

      Currently it is not known where the all derivatives of chemical X go inside the company as a whole. Every business unit knows its customers, but the flow further downstream is not known by that business. To incorporate the right storage locations and products for the optimal inventory levels, all storage locations for chemical X and its derivatives need to be known.

   1.2 **What are the optimal inventory levels when the price is seasonal and the price takes on its predicted value?**

      There is a fair amount of literature on hedging by inventory policies when prices fluctuate. However, in all articles found prices are fluctuating randomly, yet there is no seasonality in the price depicted in those papers. The mean price is assumed to be constant or have a linear trend over time and the prices fluctuate randomly along this mean. Therefore an inventory levels need to be adjusted for each quarter when prices are seasonal. To simplify the model, it is assumed that the predicted prices are accurate and take on their expected value. Since the problem is solved in a multi-echelon system, the desired inventory levels need to be set for each type of products which should be stored. Demand will be deterministic.

   1.3 **What are the optimal inventory levels when the price is seasonal and the price is assumed to be stochastic?**

      To build up on the previous question, the price will be modeled as a stochastic variable and is not assumed to always take on its expected variable. Optimizing the inventory without taking price variance into account can only achieve 80 % of the value of the optimal policy which takes uncertainty into account (Secomandi, 2010). The other variables in the model will not change compared with the static model in sub question 1.2.
3.2. Scope of the project
An important part of the project is to decide what to include in and exclude from the model. As more details are included in the model, it will become more realistic. However, it also becomes more complex. ‘To compromise the dilemma between complexity and reality, a builder should define the scope of the supply chain in such a way that it is reflective to real world dimensions, but not too complicated to solve’ (Min & Zhou, 2002). The flowchart will include more streams than the optimization model. The flowchart is made to get a complete picture of the flow chemical X through the organization. However, modeling all streams will too complex model. Therefore, only the flows of chemical X which have the biggest influence will be incorporated into the model. This will make the flowchart easier to understand, without sacrificing its usefulness.

Optimizing inventory for all products shown in the flowchart will give a complex model. To simplify the optimization model, without losing too much of its use, the 5 products are selected which are expected to give the most profit when they are adjusted to price fluctuations.

The optimization model contains all streams of chemical X and 4 derivatives in the EMEA region. Imports and exports with other regions will be taken into account as supply (incoming) and demand (outgoing), but inventory levels at those regions will not be optimized according to the situation in EMEA. Imports and exports are treated the same as external customers and suppliers.

Inventory and inventory space at a Joint Ventures (JV) will be taken into account in the optimization model when The Chemical Company has control over it. When The Chemical Company partners with another company in a JV, it can manage the inventory, but the partner company can do so as well. When the partner manages the inventory, The Chemical Company has no control over it and it will not be taken into account. If The Chemical Company has no control over the inventory levels at the JV, the stream of products will enter the model the moment they are shipped to a stock point which is in scope of the model. The joint venture will then be seen the same as an external supplier.

The optimization model will be used to set inventory targets for the different business units. Those businesses will fill in the operational execution themselves. Operational factors as lot sizes and lead time will be left out of the model, since this depends on how the businesses itself fill this in. The business themselves will try to make the targets in the most efficient way.

3.3. Deliverables
Prior to this thesis, there was no overall knowledge of the locations where chemical X and its derivatives are stored. To solve this problem a flowchart is made with the storage locations of chemical X and its derivatives. This will provide insight in the storage locations for Chemical X in the EMEA region. A model is developed to optimize the inventory according to price seasonality and an analysis is done for this quarter. The model is turned in to an Excel tool which enables the company to do the analysis in future quarters.
4. Mapping the flow of chemical X

To optimize the inventory, the storage locations need to be known. There is no information available on all the storage locations of chemical X and its derivatives. To find all relevant storage locations, the flow of chemical X will be modeled. This model will be presented in a flowchart, which can be found in
4.1. Flowchart

Mapping the flow of products through the supply chain can be done for several reasons. A well executed map can enhance the strategic planning process, ease distribution of key information, facilitate supply chain redesign or modification, clarify channel dynamics, provide a common perspective, enhance communications, enable monitoring of supply chain strategy and provide a basis for supply chain analysis (Gardner & Cooper, 2003). When making a flowchart, clear understanding of the purpose of the map, its boundaries and the benefits must be outlined. A good strategic supply chain map should be easy to build and use, comprehensive yet not overly detailed, strategic in focus, intuitive in use of visuals, effective in building alternatives, and well integrated into the strategic planning process (Gardner & Cooper, 2003).

The flowchart serves multiple goals in this thesis. First it will allow a better understanding of the flow of chemical X into the organization. People in the supply chain department know mostly where their raw materials come from and where they ship their products to. However, they don’t have a clear idea what happens further along the supply chain than what happens at their directly adjacent businesses. This flowchart shows in an organized manner where chemical X goes from its origin until the 3rd grade derivatives. Mapping the flow of chemical X will provide the supply chain departments with a broader view of the flow of Chemical X outside of their businesses. After the 3rd grade products the percentage of chemical X in the products becomes so small that other ingredients have a bigger influence on the price than Chemical X.

Supply chain mapping should be done from point-of-origin to point-of-consumption (Lambert & Pohlen, 2001). Chemical X is made by steam-cracking feedstock. The steam-crackers are the point-of-origin and therefore the start of the flowchart. The point-of-consumption will be reached at the 3rd derivative of chemical X. After the third derivative, the percentage of chemical X becomes so small that it is out of the scope of this research.

Since Chemical X diverges quickly, the scope of the flowchart needs to be limited from the beginning. To be useful, boundaries of a flowchart must be set when drawing maps of an organization (Gardner & Cooper, 2003). The end, point-of-consumption, is set at the third derivative. However, Chemical X diverges very fast. When all products until the third derivative are included the flowchart will become too wide. Therefore, locations which have a small amount Chemical X shipped between locations are not included in the flowchart.

The flowchart is made by interviewing several supply chain professionals, i.e. supply chain planners, supply chain managers and other employees with insight in the flow of goods. Supply chain professionals know to which locations they ship to and where they get their materials from. They also have data about the monthly amounts shipped between locations. Since the amount shipped between locations differs monthly, the average over the last year is taken to decide which locations to include and which to exclude from the flowchart and the rest of this thesis. To find the significant streams of Chemical X, all products will be converted to equivalents of Chemical X. The significant streams of products are the shipments between locations which are big enough to be of interest to this research. Some businesses have a big catalog of products, yet those products have the same characteristics for the most part. Those products can be aggregated on product type and an average
of the percentage of Chemical X every product type contains can be used to convert them to Chemical X equivalents.

A good flowchart would have standardized icons. These icons could come from academics, trade associations, and other sources (Gardner & Cooper, 2003). The meaning of different icons can be found in Figure 7.

An external supplier is another company supplying The Chemical Company with raw materials. This can be done in several ways. The Chemical Company can simply purchase the goods. Furthermore, businesses can agree on a swap deal with another company. With a swap deal, the supplying company does not receive (only) money, but instead they are (partly) paid back with products. If a company supplies raw materials to The Chemical Company in a swap agreement, then The Chemical Company supplies materials back to the company. There are different types of swap agreements. A geographical swap deal, tries to optimize the transportation distance. Through this agreement The Chemical Company is supplied with raw materials from a plant of the swap partner closer to The Chemical Company production site than The Chemical Company plant which makes those raw materials. The Chemical Company then supplies the swap partner with raw materials from a plant closer to the swap partner’s plants. This way, there will be fewer transportation costs. The materials taken and given don’t have to be the same products; they can be different. The companies then agree on a ratio to which products will be traded.

The merchant market is made up of all the external customers of The Chemical Company. The Chemical Company sells its products at the merchant market. Those customers can also be in other regions, although the majority of the customers are in the EMEA region. However, external customers pick up their goods at The Chemical Company and take care of their own transportation. Therefore, there is no difference between customers within the region or outside of it.

The Chemical Company businesses outside the EMEA region are outside of the scope of this project. Imports and exports have a separate icon in the flowchart (see Figure 7). The flowchart for the EMEA region can be fitted to the flowcharts of other regions if they will be made. Combining all those flowcharts together will give a global view of the flow of Chemical X (and its derivatives).

4.2. Finding products useful for hedging chemical X

All storage locations for Chemical X and its derivatives can be found in the flowchart. Including all products of the flowchart in the optimization model would result in a very extensive and complex model. To simplify the model, four products which are most suitable for optimizing the inventory of Chemical X molecules will be chosen. Since derivatives of Chemical X contain different percentages of Chemical X and the goal is to optimize the inventory of Chemical X, all products are calculated back to equivalents of Chemical X. Chemical X equivalents is the amount of Chemical X that can be found in the inventory of the derivatives. This way, a fair comparison can be made between the different products based on the amount of Chemical X they contain.

The usefulness of products for optimizing the Chemical X inventory is determined by several factors. The criteria to find the most useful products are:
- Inventory space in Chemical X equivalents
- Average available inventory space in Chemical X equivalents
- Average inventory on top of the minimum level

After speaking with professionals in different supply chain positions, 8 products in the flowchart could be of interest to this project in terms of the effect they have on the amount of Chemical X molecules in their inventory and the possibility to increase or decrease inventory. On those 8 products a further analysis will be conducted to see which four products will be used in the optimization model in chapter 5 and 7.

4.2.1. **Total inventory space in chemical X equivalents**

Including all different product types in the model will make the model more complicated. To see what effect the products have on the total amount of Chemical X molecules which can be stored, the total inventory space in Chemical X equivalents is a criterion. Derivatives of Chemical X lower in the chain contain a lower percentage of Chemical X. Per kilo of product, the amount of Chemical X molecules will be low and by that, Chemical X will have less of a price effect on the product. Products which represent a low percentage of the total inventory capacity will not have a big impact when trying to optimize the inventory on the fluctuating price, since there is not a lot freedom to adjust the inventory. As an example, increasing or decreasing the inventory of product B can only have a marginal effect compared to effect adjusting the inventory of Chemical X. The storage capacity of product B is 2.5% of the total capacity available in Chemical X equivalents, where almost 50% of the Chemical X equivalent inventory capacity is assigned for Chemical X, see Figure 8. A small adjustment in the inventory of Chemical X has already more effect as the total possible effect when increasing product B from the minimum to its maximum inventory. The total inventory capacity makes up the limit of the maximum effect of adjusting the inventory. Products for which the maximum effect is already limited compared with other products will be left out to keep to model simple. Figure 8 shows that products B, C, G and H have a more limited maximum effect compared to the 5 other products.

![Figure 8: Total inventory space (chemical X equivalents)](image-url)
4.2.2. Average available inventory space in chemical X equivalents

The total inventory capacity gives the maximum storage capacity in Chemical X equivalents. However, the amount of inventory which is available determines how much inventory can be added to optimize for price fluctuations. Some products might have a big percentage of the total storage capacity. Yet, due to a long lead time it might be necessary to hold more products on stock. This causes there to be less room for adjusting the inventory to price seasonality. The inventory level differs every month and consequently the free available inventory space is also different every month. To eliminate the monthly fluctuations in inventory levels, the average inventory over the last 3 years is used to calculate the average available inventory space for adjusting inventory to price fluctuations. This available inventory space can be used to increase inventory when prices are expected to go up. In Figure 9 it can be seen that product B, C, G and H have generally only a very small portion of the total available inventory space of Chemical X equivalents. On average, 60% of the freely available inventory space is assigned to Chemical X. Product H has only 1.3% of the total free inventory space available, on average.

![Average available inventory space](image)

Figure 9: Average empty inventory space (chemical X equivalents)

4.2.3. Average inventory on top of the minimum level

The available inventory space (§4.2.2) makes up the average space available to adjust when prices go up. However, when prices go down, it is optimal to lower the inventory levels. Therefore, the average amount by which the average inventory can be adjusted downwards is a good measure. The average inventory on top of the bare minimum will give the possible amount by which inventory on average can be decreased when prices go down. The percentage of the total amount accounted to one product is divided more equally for this measure than the other 2 measures, see Figure 10. Chemical X still has the biggest piece of the total inventory above minimum; however products F and D almost have the same amount of inventory available to decrease the inventory, Figure 10. Products B, C, G and H have do not have a big effect on the total amount of inventory which can be decreased when prices go down.
Figure 10: Average inventory level above minimum (chemical X equivalents)

4.3. Conclusion

Based on the figures above, most Chemical X molecules can be stored as pure Chemical X. When it is not stored as pure Chemical X, but as a derivative, products with a substantial effect on the total available storage capacity of chemical X molecules are products, A, D and F. The other products do not have a big effect. The products which have a substantial effect on the average available inventory space are products X, A, D, F and G. When decreasing downwards, products X, A, D and F have the biggest influence on the total space available to decrease the inventory. Based on the above analysis, the optimization model is built for Chemical X and derivatives A, D, F and G.
5. Optimization with static prices

In this chapter the optimal inventory levels are set when prices fluctuate seasonally in a static environment. It is assumed that price can be predicted perfectly. This means that the prices take the actual values predicted when optimal planning is made. This simplifies the model by removing all uncertainty. The model is developed to be used for the aggregate production planning. Aggregate production planning is made for the intermediate future, often 3 to 18 months ahead of time (Wang & Liang, 2005). This model covers a period of 6 months. A difference should be made between the first three months of the model and the last three months of the model. In the first three months products can only be bought to be used in the last three months of the model.

5.1. Model

The aim of the model is to minimize the costs of raw materials plus the holding costs, and by that maximizing the profit since the revenues will not change. In this problem the company produces the products itself. On top of that, products can be purchased from 2 other suppliers. Sometimes the price of other suppliers can be lower than the production costs of The Chemical Company for that product. This can happen because of scale advantages the competitor has. Chemical X is a commodity; hence, products are expected to have uniform quality and do not differ between the different suppliers. Therefore, products produced and ordered are interchangeable. This also applies for the derivatives of chemical X.

The model will be used for the strategic aggregate planning of the desired inventory levels for the following quarter. Because of the strategic nature of the model, operational factors such as lot sizes and lead time will be left out of the model. The production and inventory targets will be given to the businesses’ managers who are responsible for the different products. The inventory target is set for multiple businesses and the businesses itself take care of the operational execution of the targets. Defining operational policies will be hard, since every business uses more ingredients than just chemical X. Those raw materials are sometimes delivered by pipeline where a minimum amount always needs to be taken. Since taking all those constraints into account will make it very complex, the focus in this thesis is on the strategic planning, and the operational factors will be left out.

To see how the optimized model performs compared to the current situation, both situations need to be defined:

- Current situation: Buy/produce exactly for the demand which is forecasted for that month, the inventory level is kept at the same level as at the beginning of the quarter.
- Optimized situation: Buy/produce the optimal amounts of products according to the seasonal price changes. Look one quarter ahead to see if it is favorable to buy/produce more for the next quarter.

5.1.1. Assumptions

In this section all assumptions of the static linear programming model are combined. The model is based on the basic Linear Programming Model for Aggregate Inventory Planning described in Silver et al., (1998). The assumptions used in the Linear Programming Model in this thesis are:

- Demand is deterministic
  It is assumed that the demand for every period is known. The demand differs month to month, but the demand for every month is known when the inventory optimization is done.
• **Demand occurs once a month at the end of the month**
  The demand occurs at the end of the month and is realized after the inventory of that month is replenished.

• **Demand must be met at all times, backorders are not allowed**
  Since demand is deterministic this assumption can be fulfilled. It is exactly known how much demand will occur, so enough supplies can be ordered to fulfill all demand.

• **Prices are predicted perfectly**
  The prices are seasonal, but there is no variance in the price. The prices can be predicted perfectly and are known when the optimization is done. This assumption will be relaxed in chapter 7.

• **Supplies are delivered right before demand is fulfilled**
  Products are ordered once a month and arrive at the end of the month right before demand occurs. Hence, the inventory in period \( t + 1 \) is equal to \( I(t + 1) = I(t) + u(t) - D(t) \).

• **Suppliers can always fulfill the orders placed**
  Products which are ordered at suppliers will always be delivered in the same month. This means that products ordered from suppliers can always be used to fulfill the demand of that month.

### 5.1.2. **Notation**

- \( C_{\text{tot}} \): Total costs
- \( C_{\text{ptl}} \): Extra capital needed at end of first quarter
- \( i \) \( \in \{1,2,3,4,5\} \): Type of product
- \( j \) \( \in \{1,2,3\} \): Different suppliers
- \( r \): Cost of capital per year (%)
- \( I_{\text{max},i} \): Maximum inventory level for product \( i \)
- \( I_{\text{min},i} \): Minimum inventory level for product \( i \)
- \( I_i(t) \): Inventory level of product \( i \) at time \( t \)
- \( I_{\text{planned},i}(t) \): For \( t \in \{1,2,3\} \) Planned inventory levels from previous production plan for product \( i \) at time \( t \)
- \( h_i(t) \): Holding costs product \( i \) at time \( t \)
- \( u_{i,j}(t) \): Units ordered of product \( i \) at supplier \( j \) at time \( t \)
- \( u_{\text{min}}(i,j) \): Minimum amount ordered of product \( i \) at supplier \( j \) per month
- \( p_{i,j}(t) \): Price per unit of product \( i \) at supplier \( j \) at time \( t \)
- \( Q_i(t) \): For \( t \in \{1,2,3\} \) capacity available in first 3 months of the analysis of product \( i \) at time \( t \)
- \( D_i(t) \): Demand for product \( i \) at time \( t \)
5.1.3. Mathematical problem formulation

The model consists of 5 different types of products, where product 1 is chemical X and the other products are the derivatives of chemical X. Each product can be ordered at three different suppliers, which includes The Chemical Company itself as a producer 1. The inventory targets are optimized for 1 quarter at a time, by adjusting the amounts ordered in two quarters. At the beginning of the quarter, the production/procurement for the next quarter is optimized, i.e. at the beginning of the fourth quarter the production/procurement is optimized for materials needed in the first quarter.

To minimize the costs, the price of the products at each time is important. The amount ordered multiplied with the price at that time makes up the costs of the raw materials needed. However, it can be favorable to store products for the next period. The economic interpretation of storage is the difference between its production and consumption in the current period, i.e., the amount of a commodity that is carried over to the next period (Williams & Wright, 1991). Storing products gives an inventory cost per unit which is a percentage of the value of the inventory, see equation (2). Combining the formulas for the ordering and holding costs leads to equation 1. In the first quarter of the model only the inventory which will be used in the second quarter needs to be taken into account. The goal is to optimize the procurement of the products for quarter 2 \((t=4,5,6)\), so only the products which are ordered to be used in the second quarter of the model need to be considered in the costs model.

\[
C_{tot} = \min_{u_{i,j}} \sum_{t=1}^{6} \sum_{i=1}^{5} \sum_{j=1}^{3} u_{i,j}(t) \cdot p_{i,j}(t) \\
+ \sum_{i=1}^{3} \sum_{t=1}^{3} (I_i(t) - I_{i,planned}(t)) \cdot h_i(t) + \sum_{t=4}^{6} \sum_{i=1}^{5} I_i(t) \cdot h_i(t) 
\]  

(1)

Where

\[
h_i(t) = p_i(t) \cdot \left( \frac{r}{12} \right) 
\]  

(2)

The inventory space is capacitated upwards as well as downwards. The minimum inventory level of product, \(I_{min}\), cannot be lower than the sum of the dead stock of the tanks. Dead stock is the amount of inventory which cannot get out of the tank when the tank operates. It is possible to get the dead stock out, however, the tank will not operate properly anymore. This dead stock can be in the pipes of the tank or just the bottom of the tank which cannot be pumped out. Therefore, reducing the inventory lower than the dead stock will create a lot of extra constraints and costs that are not in the interest of this research, which tries to optimize inventory according to seasonal prices. The maximum inventory level is the sum of the tank sizes of all tanks in EMEA region for a product. Most tanks can only be loaded until a certain percentage of their volume due to safety regulations. The percentage up to which level they can be filled is called the fill rate. The theoretic volume of the tank multiplied with the fill rate will give the maximum amount of product which can be stored in a tank.
Equation (1) is therefore constrained by:

\[ I_i(t) \leq I_{\text{max},i} \]  \hspace{1cm} (3)

and

\[ I_i(t) \geq I_{\text{min},i} \]  \hspace{1cm} (4)

Where

\[ I_i(t) = I_{i,\text{planned}}(t) + \sum_{j=1}^{3} u_{i,j}(t) \] \hspace{1cm} for \( t \in \{1,2,3\} \) (5)

And

\[ I_i(t) = I_i(t-1) + \sum_{j=1}^{3} u_{i,j}(t) - D_i(t) \] \hspace{1cm} for \( t \in \{4,5,6\} \) (6)

The inventory which is held in periods 1,2 and 3 and not meant for optimizing raw material costs of periods 4,5 and 6 is \( I_{i,\text{planned}}(t) \). This inventory is already planned a quarter upfront. On top of this inventory, products can be stored to optimize the production and procurement of products for the next quarter. \( I_{i,\text{planned}}(t) \) is a given number for periods 1,2 and 3. The total inventory is still limited by equations (3) and (4).

In the model \( u_{i,j}(t) \) is the amount ordered of product i at supplier j in time period t. With each supplier, contracts are negotiated which specify the maximum and minimum amount which can be ordered each month. The amount ordered is, therefore, limited by equations (5) and (6), respectively the minimum and maximum amount ordered of product i at supplier j. The Chemical Company itself has a rate at which factories can run. The Chemical Company can shut down its factories, so the theoretical minimum amount produced in a month would be 0. However, when the decision is made to shut down a factory a lot of other costs will come into account. This is not of interest to this research. The minimum production rate is, therefore, the rate at which a factory can run when operations do not need to be shut down and no big extra costs occur due to the reduction of the production rate.

\[ u_{i,j}(t) \geq u_{\text{min},(i,j)} \] \hspace{1cm} for \( t \in \{4,5,6\} \) (7)

\[ u_{i,j}(t) \leq u_{\text{max},(i,j)} \] \hspace{1cm} for \( t \in \{4,5,6\} \) (8)

In periods 1, 2 and 3 the model only takes into account the production and procurement of products used in the next quarter. The planning and production of products used in periods 1, 2 and 3 will not be included. The aggregate planning for periods 1, 2 and 3 already happens before period 1 starts and that production plan will be taken as input for this model. The aggregate planning already made for period 1, 2 and 3 fulfills the restrictions described above.

The current production plan for production in first three periods for materials also used in periods 1,2 and 3 changes the ordering and inventory restrictions described above for \( t = 1, 2, 3 \). The maximum amount ordered in months 1, 2 and 3 is the amount of unused production capacity, \( O_{i,j}(t) \). This overcapacity can be used to produce and procure products for the next quarter. For months 1, 2 and 3 the units ordered need to be smaller than the overcapacity:
For the first quarter \( t=1,2,3 \) of the analysis the amount of products which need to be specially ordered will be given. These extra orders come on top of the plan which is made a quarter before. For example, if the model is ran for the quarter 4. Then inventory can be bought/produced and stored in quarter 3 for quarter 4 in the model. Before the model is run, there already is a plan for quarter 3. On top of that plan, the model will specify the amount of products which need to be produced or bought. For quarter 4, the total amount of units which need to be produced/bought are given and not just the extra units.

Next to the production and inventory restriction there is also a capital restriction. The chemical industry is a capital intensive industry. Because of the amounts of capital which are already needed to operate, all capital expenses are closely watched by upper management. When the decision is made to invest capital in inventory for the next quarter, the amount of money which can be used to buy/produce extra products is constrained by a limit given by upper management.

\[
\sum_{t=1}^{3} \sum_{i=1}^{5} \sum_{j=1}^{3} u_{i,j}(t) \ast p_{i,j}(t) < Cptl_{\text{max}}
\]

5.1.4. Calculating expected future prices

All variables above are given values or will be calculated as a result of the model, except the price. In chapter 2.1 the seasonal behavior of the price of chemical X is explained. This analysis focuses only on the monthly and 3 month changes of the price and does not focus on actual prices of chemical X. The future prices need to be predicted for period 2 to 6. Since an analysis has been conducted for the month to month change and 3 month change, predicted month and 3 month price changes need to be combined to calculate the price for periods 5 and 6.

The price at month 1 is known. For period 2 we add the expected monthly change to the price of period 1. A decrease in price is represented by a negative number. For period 3, we add the change of month 1 to 2 and the month to month change from month 2 to 3. For month 4, the 3 month change can be added to month 1. Predicting one variable for 3 months (3 months change) is a better predictor for the 3 months change than adding 3 times the month to month change. Adding 3 times the month to month change gives three times variation.

The price in month 5 is calculated by first adding the 1 month change and after that the 3 month change from month 2 to 5. One month price changes are easier to predict when they are close by. Predicting the month to month price change over three months brings a lot more uncertainty. Therefore, first the 1 month price change is added and then the change for months 2 to 5. For period 6 the month to month change of period 1 to 2 and 2 to 3 are added first and then the 3 months change is added. This way the prices are expected to be more accurate.
5.1.5. Key Performance Indicators (KPI’s)

There are 3 important measures by which the company will decide if the optimization will be done. Those 3 financial measures are:

- **Change of operating income**
  The change in operating income describes the effect on the company’s operating efficiency. Operating income is used to measure the company’s profitability. The model minimizes the costs and by doing so it maximizes the operating income. The chemical industry is a capital intensive industry, where a lot of the capital is financed by debts. A common measure used in loan covenants is the ratio of Debt/operating income. This ratio gives an indication of the ability of the company to pay off its debt. An increase of the operating income will decrease this ratio, which will increase the credit rating of the company.

- **Change of Cash flow in each quarter**
  The chemical industry is a capital intensive industry, which limits the amount of free cash in the company. A lot of the capital needed is financed by loans. An increase in cash flow will give the company the ability to pay back the loans or invest the money in new projects.

- **Capital investment return (CIR)**
  Important for the company is the ratio between the investment and the earnings on this investment. The capital needed to buy extra inventory in the first quarter of the model for the next quarter is the investment and the return is the amount the increase of the operating income.

5.1.6. Calculating the KPI’s

- **Change of operating income**
  The operating income is affected by the extra holding costs in the model and the fewer costs spent on raw materials. The operating income of the optimized situation will be compared with the current situation. In the optimized situation products are bought when it is optimal comparing the holding costs with the price difference. Products are bought periods upfront and then stored until they are used. Therefore the raw material costs will decrease, but the total inventory costs will increase. The change in operating income is:

  \[
  \text{Change operating income} = \text{less material costs} - \text{extra holding costs}
  \]

  \[
  \text{Change operating income} = (D(t) - u(t)) \times P(t) + (I(t) - I'(t)) \times h(t) \tag{11}
  \]

  The first part of equation 11 indicates the difference of the amount of products multiplied with the price. This gives the change in costs spent d on raw materials every month. \(I'(t)\) is the inventory level in the current situation. The difference in the amount on inventory times the holding costs makes up the extra holding costs.

- **Change of Cash flow**
  The change in the amount of cash flowing through the company is important for the liquidity of The Chemical Company. The amount of cash spent every month differs only because of the
amount bought every month in the current and optimized situation. In the current situation every month an amount equal to the demand of that month is produced/ordered. The difference between the demand and the amount ordered in the optimal situation times the price is, therefore, the change in cash flow for every month.

Change cash flow = Less raw material costs

\[
\text{Change cash flow} = (D(t) - u(t)) \times P(t)
\]  

(12)

- **Capital Investment return (CIR)**

To see if the company is making money, it is important that the return on the money invested is greater than the cost of capital (r). When the return on the capital invested is greater than the costs of the company, it is making money.

\[
CIR = \frac{\text{Change operating income}}{\text{Extra working capital (t = 3)}}
\]

See equation 11 for the change in operating income. The value of the extra inventory on the balance is the products extra on inventory on top of the current situation times the price at that moment (equation 13).

\[
\text{Extra capital on balance(t)} = (I_{p}(t) - I(t)) \times p(t)
\]  

(13)

Hence, CIR becomes:

\[
CIR = \frac{(I_{p}(t) - I(t)) \times p(t)}{(D(t) - u(t)) \times P(t) + (I(t) - I'(t)) \times h(t)}
\]  

(14)

5.2. Results

In this chapter the model described in chapter 5.1 will be run. The performance of the model will be measured according to the KPI’s described in 5.1.5. Also it will be analyzed in which quarter the biggest gains can be expected. The model includes the five products which are expected to be most useful. To see for which products it is profitable to build up inventory, one performance analysis is conducted per product. Every product is analyzed according to the KPI’s and the effect they have on the total of the five products. If the effect on total profit is small, The Chemical Company needs to decide if it is worth incorporating that product or to just optimize for the other products. Next to this analysis, an analysis to determine what the gain would have been in the last 3 years if the inventory would have been optimized with the model is conducted. The period for which this is done is June 2010 to June 2013. Additionally, a comparison between the performance of optimizing on the average price and optimizing on the lower or upper bound of the confidence interval is made.

The starting price in the model is the price at the beginning of each quarter in 2013. So for optimizing quarter 1, the price in October 2013 is used. And for optimizing Q2, the January 2013 price is the starting price, \(p_{i,1}(1)\).
5.2.1. Quarterly Analysis

In this part of the research it is determined in which quarters it is optimal to adjust the inventory of Chemical X (derivatives). Due to the seasonality, it will not be efficient to build up stock every quarter. Furthermore, the difference between the upper and lower bound of the confidence interval is bigger in quarter 2 and 3. This will lead to more deviation from the prediction and therefore bring more risk with the investment. Thus, for every quarter an optimization is done for the average and upper and lower bound of the confidence interval. The results of the analysis can be found in Appendix B: CIR and savings per Quarter. The differences between the upper and lower bounds will be discussed in chapter 5.2.2. In this paragraph the quarterly results for the average price is discussed.

Buying or producing products used in quarter 2 (Q2) in advance can save The Chemical Company money. The price at the beginning of the quarter 1 (Q1) is relatively low, so it is optimal to buy in the beginning of Q1. Prices in the quarter 2 are going down. However, the prices in the beginning of the first quarter are lower than in the beginning of second quarter. Ordering or producing products in the beginning of quarter 1 and storing the products to use them in beginning of quarter 2 is therefore optimal on average. However the forecasted return and the return that The Chemical Company would actually have made in last 3 years differ significantly. In 2012 the return would have been almost double the prediction, when the optimization would be done on the average price change. In 2010 the return would be 1.4%, which is only 10% of the predicted return. This bigger variation in return is due to the bigger variation in the price change in Q2. When the

No stock is bought at the end of Q2, when optimizing the procurement and production planning for Q2 and Q3. This means no money is invested in stock in Q2 and no capital is used. Small savings are forecasted by optimizing the production plan during Q3 according to the price changes. However in the last 3 years those inventory levels would have resulted in a loss twice compared to the current situation. The model shows the same results when the optimization is conducted for Q3 and Q4. No money is invested in quarter 3, and optimizing the procurement and production in quarter 4 resulted in a loss 2 of the last 3 years.

The biggest gains can be expected when optimizing the procurement for Q1 in Q4. The returns on investments are high. Investing money in Q4 will give a return forecasted CIR of 20.4%. So for every 100 euro invested, the operating income is forecasted to increase with 20.4 euro. Since the money is invested at most for half a year, the equivalent yearly CIR would be 40.8 percent. Looking to the last 3 years, it can be seen that even in 2012-2013 were prices increases less than expected, still a CIR of 7% is achieved in 6 months.

The model forecasts the biggest improvement of the operating income when products are bought in Q4 to be used in Q1 of the next year. Optimizing the production and procurement in Q1 and Q2 also has a positive result. However, when the inventory and production in Q4 is optimized for Q1, this will reduce the positive effect from Q1 to Q2. When the inventory in Q1 is full due to the extra products coming from Q4, there will less space to optimize for Q2 and the savings in Q2 will be less. The analysis Appendix B: CIR and savings per Quarter assumes no optimization in previous quarters.

5.2.2. High, Low, Average analysis

In the price analysis in 2.1 three different lines are given, the average price change, the lower bound and the upper bound of the one sigma confidence interval of the price change. An analysis is
conducted to see the differences between optimizing on the different expected price. In Figure 11 the predicted price change is shown with the actual price change in the last three years. This shows the price for quarter 4, where the October price of Chemical X is set as 0 for all years. The blue line shows the forecasted price change compared with October.

![Figure 11: Forecasted price Q4 – Q1 compared with prices fluctuations in Q4 – Q1 of last 3 years](image_url)

In Appendix B: CIR and savings per Quarter the results of the analysis can be found. When it is efficient to buy inventory a quarter upfront, optimizing on the lower bound of the CI is expected to underperform the average. Optimizing on the lower bound is used as a worst case scenario, if the price goes less up as expected. Optimizing on the lower bound underperforms compared to optimizing on the average, even when the prices increase less than expected (2012-2013). Optimizing for the upper bound gives higher profits in 2010-2011. However, in years when price does not go up significantly in the second periods 4, 5 and 6 of the model, less profit or even losses are made. Optimizing on the higher price can allow greater profit, yet there it also more risk associated with.

### 5.2.3. Ordering Quantity

From paragraphs 5.2.1 and 5.2.2 it can be determined that the biggest gain will be in quarter 4. In the other quarters the returns will be low. When optimizing on the average forecasted price, the ordering policy in Q4 will be to order as much as production, inventory and capital restrictions allow in November. When capital, inventory and capital restrictions allow, then order or produce products in December. Ordering products in October will only be done if not enough products can be ordered in November in December. It is still better to order or produce products in October than when you have to make or order them in Q1, but ordering in November or December is preferable. In Q1 you keep high inventory until the end of the quarter, since prices are expected to go up the whole quarter.

When optimizing on the lower bound of CI of the forecasted price changes, expecting the prices to go up less than the expected average price change, you first order and produce as much as restrictions allow you in December. If the restrictions allow, the inventory should be filled up in November. At last products to be used in Q1 should be ordered or produced in October when the
optimization is done on lower bound. The lower bound expects prices to decrease in Q4 and prices to increase from December on. Therefore, it is optimal to order/produce products in December.

When optimizing on the upper bound of CI of the forecasted price changes, products are first bought in November. When all restrictions are filled for November and it is optimal to order more products in quarter 4, products will be ordered in October. When inventory and capital restrictions are not met yet, more products will ordered in December. Even though the price is expected to go up from October to November, products will still first be ordered in November, because the price increase is less than the holding costs for one month.

5.2.4. Analysis per product
The model is optimizing the production and procurement of 5 different products. To see what effect every single product has on the total savings and investments needed, an analysis per product is conducted. The analysis is done for the average forecasted price change from Q4 to Q1, where the starting October price is the price of Chemical X in October 2013. To see what the results would have been in the last three years per product, the analysis is also conducted with the prices in last 3 years. The results with the prices of 2012, 2011 and 2010 can be found respectively in Table 3, Table 4 and Table 5.

From the first analysis in paragraph 4.2.1, it was expected that Chemical X has the biggest effect of the 5 products. Almost 50% of the total available storage capacity is assigned for pure Chemical X and on average 60% of the total available inventory space is available for Chemical X. In Table 2 is can be seen that the total effect on change in cash flow and operating income is even higher, above 70%. If The Chemical Company would have been optimizing the production in the last three years for all 5 products, Chemical X would have accounted for 70% to 75% of the total increase in cash flow and 70% to 80% of the total increase in operating income. However, the investment is between 60% and 65% percent of the total needed investment. This leads to a higher increase in operating income per unit of capital invested. Table 6 shows that Chemical X has the highest expected CIR and also in the last three years it would have had the highest increase of operating income per Euro invested.

<table>
<thead>
<tr>
<th>Product</th>
<th>Δ Cash flow</th>
<th>Δ Operating income</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical X</td>
<td>72%</td>
<td>74%</td>
<td>64%</td>
</tr>
<tr>
<td>F</td>
<td>13%</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>G</td>
<td>2%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>D</td>
<td>7%</td>
<td>6%</td>
<td>12%</td>
</tr>
<tr>
<td>A</td>
<td>6%</td>
<td>6%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 2: Per product analysis with forecasted price (% of total)

<table>
<thead>
<tr>
<th>Product</th>
<th>Δ Cash flow</th>
<th>Δ Operating income</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical X</td>
<td>73%</td>
<td>74%</td>
<td>61%</td>
</tr>
<tr>
<td>F</td>
<td>13%</td>
<td>13%</td>
<td>15%</td>
</tr>
<tr>
<td>G</td>
<td>1%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>D</td>
<td>7%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>A</td>
<td>6%</td>
<td>6%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 3: Per product analysis with 2012 price (% of total)

<table>
<thead>
<tr>
<th>Product</th>
<th>Δ Cash flow</th>
<th>Δ Operating income</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical X</td>
<td>70%</td>
<td>72%</td>
<td>63%</td>
</tr>
<tr>
<td>F</td>
<td>13%</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>G</td>
<td>2%</td>
<td>4%</td>
<td>13%</td>
</tr>
<tr>
<td>D</td>
<td>8%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>A</td>
<td>7%</td>
<td>7%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 4: Per product analysis with 2011 price (% of total)

<table>
<thead>
<tr>
<th>Product</th>
<th>Δ Cash flow</th>
<th>Δ Operating income</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical X</td>
<td>70%</td>
<td>72%</td>
<td>63%</td>
</tr>
<tr>
<td>F</td>
<td>13%</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>G</td>
<td>2%</td>
<td>4%</td>
<td>13%</td>
</tr>
<tr>
<td>D</td>
<td>8%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>A</td>
<td>7%</td>
<td>7%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 5: Per product analysis with 2010 price (% of total)

Product F gives the second biggest gain in operating income and cash flow, about 13%. However, it also uses a big part of the total capital investment, around 14%. Product A only makes up for 6% of the increase in operating income and cash flow and only needs 6% the total capital investment. This
leads to a higher return for product A compared with product F. Table 6 shows a forecasted CIR for product A of 20%, where product F has 18%. In the last three years, product A always would have had a higher CIR.

The returns on per Euro invested for product G and D is 50% or less compared to Chemical X. They have the least influence on the total gain in cash flow and operating income, but especially product D takes up a considerable amount of the total amount of capital invested. Considering the high cost capital a chemical producer has, it is doubtful if it is useful to invest in products G and D.

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>F</th>
<th>G</th>
<th>D</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>24%</td>
<td>18%</td>
<td>8%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>2012</td>
<td>9%</td>
<td>5%</td>
<td>1%</td>
<td>2%</td>
<td>6%</td>
</tr>
<tr>
<td>2011</td>
<td>31%</td>
<td>22%</td>
<td>6%</td>
<td>10%</td>
<td>25%</td>
</tr>
<tr>
<td>2010</td>
<td>21%</td>
<td>17%</td>
<td>9%</td>
<td>10%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Table 6: CIR per product

*The absolute numbers of the change in operating income, cash flow and invested capital can be found in appendix D (Confidential)*

5.3. Conclusions

Optimizing Chemical X (and its derivatives) according to price seasonality can allow a gain for quarters 4 to 1 and 1 to 2. However, when the optimization is done for quarter 4 to 1, the inventory will be filled up in quarter 1. This results in almost no gain when also optimizing quarter 1 to 2. Optimizing from quarter 4 to quarter 1 allows a greater gain in cash flow and operating income. The CIR is also higher. Therefore, it is optimal to invest in quarter 4 to quarter 1. Optimizing for the average expected price will give a higher return than optimizing for the lower bound of the confidence interval. Optimizing for the higher bound gave a higher return in 2010-2011. However, this also creates a bigger risk. If the price goes up less than expected, the chances of a loss are higher.

Optimizing on the average price will lead to an ordering policy where you will first order in November until all restrictions are filled. If it is favorable to order more products, it is best to order them in December. When inventory, production, and capital restrictions allow, orders will be placed in October when there is no other option.

When examining the products individually, Chemical X gives the highest return on capital invested when optimizing for the price seasonality. After chemical X, product A is the best option, but product A does not have a lot of storage capacity available. This means the effect on the overall savings will be low. Product F has more storage capacity and gives a bigger gain in operating income and cash flow, but has less return on capital invested. Products G and D give a lower return and are the least favorable to use when trying to optimize the procurement and production of chemical X (derivatives) according to the price seasonality.
6. Sensitivity analysis
To assess the results and get a better understanding of the relation between input variables and the output, a sensitivity analysis is performed. In the next section the effects of several factors are discussed.

6.1. Analysis for different prices
The solution given by the LP-model is optimal if the price takes the average forecasted price. However, for The Chemical Company it is useful to see how the performance is with those inventory levels when the price does not take the exact values. The price change is assumed to be normal distributed, with mean equal to the average price change and sigma equal to size of the one sigma confidence interval. To do this 10000 years of prices are simulated. With those 10000 price paths, the costs are calculated when ordering according the amounts proposed in the LP model. In Table 7 the results of this analysis can be found.

<table>
<thead>
<tr>
<th></th>
<th>Δ Cash flow</th>
<th>Δ Operating income</th>
<th>CIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td></td>
<td></td>
<td>47%</td>
</tr>
<tr>
<td>min</td>
<td></td>
<td></td>
<td>-2%</td>
</tr>
<tr>
<td>μ</td>
<td></td>
<td></td>
<td>21%</td>
</tr>
<tr>
<td>Std dev</td>
<td></td>
<td></td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 7: Analysis with different prices

Table 7 shows the change in cash flow, change in operating income and the CIR. In 4 out of the 10000 simulations there would decrease of the operating profit with those desired inventory levels. This also results in a negative CIR. The loss is however still small. The mean CIR in the analysis is 21%, with a standard deviation of 6%. The effect on the cash flow is positive in all cases. This means the raw material costs are lower in all cases; however, in 4 cases, the extra holding costs were higher than the decrease of the raw material costs, which led to a negative effect on operating income. The probability that The Chemical Company will lose money is small.

6.2. Shadow prices
To see which restrictions have the biggest effect on the objective function, the shadow prices are calculated. The shadow prices give the marginal costs of a unit extra or less for the constraint. As an example, the costs for adding one unit to the inventory capacity should not be higher than the shadow prices. The shadow price for the inventory constraint gives the gain of adding one unit to the inventory space.

The constraints with the highest shadow prices are the minimum inventory level at the end of the optimization. The lower this constraint is, the fewer products need to be bought in that quarter. However, lowering this constraint will lead to an unequal comparison between the current situation and the optimal situation. In the optimal situation fewer products will be bought than in the current situation. The current situation assumes exactly the demand is bought in each month. Therefore the inventory level stays the same. In the optimal model, the starting inventory level is the same. When the end inventory level is lower, this means fewer products are bought, since the demand each is the same. The inventory constraint of the last month therefore cannot be lowered. Lowering the inventory constraint further can also lead to problems with service levels.
Next to the last month minimum inventory constraint, the maximum inventory capacity constraints have a high shadow price. Increasing the inventory capacity will decrease the costs in this model. However the costs of adding capacity are not taken into account. Therefore a comparison can be made between the extra gain and extra costs when the maximum inventory capacity is increased.

6.3. Capital constraint
The chemical industry is a capital intensive business. Therefore capital is not unlimited available. In the above analysis the amount which could be ordered and produced was limited by the production and inventory capacity. In this part an analysis be conducted in which the amount of capital is restricted. Figure 12 shows the results of different amounts of capital available to invest. The maximum value on the x-axis (100%) is the amount of capital which is invested when there is no restriction on the available capital. The amount produced and ordered is then restricted by inventory and production constraints. Figure 12 shows that the more capital is invested, the lower the CIR will be. However, the total savings increase. The CIR decreases, because the model will first store products for the biggest price difference, i.e. if the price difference is the biggest between November and March then your return will be high. However, the price change between November and February is smaller; it is still worth investing, because it will result in a gain. The return will then be lower, but the overall amount of money saved is higher. This explains why the savings get bigger and the return decreases. The cost of capital of The Chemical Company will decide the optimal amount of capital for which products should be bought in quarter 4.

6.4. Amount of inventory in \( t=1, 2, 3 \)
The amount on inventory in the first three months of the model determines the amount of inventory which can be used to add products to be used in the next quarter. In Figure 12 the primary y-axis gives the change in million of Euros for the cash flow and Operating income. The values for the CIR are shown on the secondary y-axis. The fill rate of the inventory gives the percentage of the total capacity which is filled with stock before the optimization model is ran. The fill rate is 0% when the inventory is equal to the dead stock. As can be expected, the cash flow and operating income decrease when the fill rate increases. If less inventory space is in use before the optimization is done, more products can be stored for the next quarter. With increasing prices as from Q4 to Q1, this will improve the cash flow and lead to a higher operating income. When the inventory is filled for a high percentage before optimization the cash flow and operating income will improve less as with a low fill rate. The Capital investment return is increasing when the fill rate is less than 50%. This is due to the production constraints. With a low fill rate, a lot of the products will be produced for the next quarter. This leads to that products will be produced in less optimal months. When optimizing from Q4 to Q1 this means products are produced in December and October, while November has the lowest prices. The return will be lower, but overall
6.5. **Magnitude of price change**

When multiple chemical producers optimize their inventory according to the seasonality in the price, the price may smooth out and the seasonal effect becomes less. The demand will go up in Q4 and by that the price will go up too if supply stays the same. In Q1 the price will go down, because of the lower demand. In Figure 13 the magnitude of the seasonality in the price is represented on the x-axis, where 100% represents the monthly changes described in chapter 2.1. At 50%, the price changes are half of the price changes in chapter 2.1. When magnitude of the seasonal effect becomes less big, but the optimization will still be done on the current price forecasts, the CIR will decrease linear with the smaller price changes, see Figure 13. The costs saved show a little curve in the line. When the magnitude of the price changes becomes bigger, the cost savings increase slightly slower.

![Magnitude of seasonal effect graph](image)

**Figure 13: magnitude of price changes**

7. **Proof of concept: Optimization of dynamic case**

In this chapter optimal inventory levels are calculated when prices fluctuate seasonally in a stochastic environment. This means that the prices are not predicted perfectly, but it is assumed that the distribution of the price changes is known. The model developed in this chapter is an extension of the model developed in chapter 5. In 7.1 the full model is discussed. In 7.2 a proof of concept is given for solving the model. This is done by solving a simplified version of the model, which later can be extended to the full size model described in 7.1.

7.1. **Dynamic Model**

At each period t, decisions about the inventory level should only depend on information available at the time of the decision. This principle is called the non anticipativity constraint. Based on the historical prices before time t, a distribution of the price change is made. The dynamic model is an extension of the deterministic model presented in chapter 5. The objective function, equation 15, changes in two ways from the deterministic model. First, the goal will be to minimize the expected costs. The expected costs are minimized, because we assume the company is risk-neutral. All other variables are deterministic. This means that if the expected costs are minimized the profit will be maximized. A risk neutral person will invest when the expected revenues are higher than the expected costs (Rabin, 2000).
In the dynamic model the movement of the price will be uncertain. The movement of the price, $\Delta \tilde{P}_{i,j}$, is modeled as a normal distribution, with a specified mean and standard deviation. An analysis has been conducted to estimate the month to month changes and the 3 month change. To predict the price until period 6, both the month to month and the 3 month change are used, see chapter 2.1. The price in periods 2 and 3 is calculated with only the month to month change, equation 16. Equation 17 is used to calculate the prices for periods in the second quarter of the model.

\[
\begin{align*}
\tilde{P}_{i,j}(t) &= \tilde{P}_{i,j}(t - 1) + \Delta \tilde{P}_{i,j}(t - 1, t) & \text{for } t = 2, 3 \\
\tilde{P}_{i,j}(t) &= \tilde{P}_{i,j}(t - 4) + \Delta \tilde{P}_{i,j}(t - 4, t - 3) + \Delta \tilde{P}_{i,j}(t - 3, t) & \text{for } t = 4, 5, 6
\end{align*}
\]

With

\[
\begin{align*}
\Delta \tilde{P}_{i,j}(t - 1, t) &\sim N(\mu(t - 1, t), \sigma(t - 1, t)) \\
\Delta \tilde{P}_{i,j}(t - 3, t) &\sim N(\mu(t - 3, t), \sigma(t - 3, t))
\end{align*}
\]

The holding costs are dependant of the price at period t. With the price being stochastic, the holding costs become stochastic part too. In the objective function the holding costs are already shown as equation 20 to keep the amount stochastic variables in the objective function limited to only $\tilde{P}_{i}(t)$.

\[
\tilde{h} = \tilde{P}_{i}(t) \ast \left( \frac{r}{12} \right)
\]

The inventory and production constraints, shown in equation 3 to 9, also hold for this model. The production capacity and inventory space do not depend on the price. Since the price is the only variable that changed compared to the static model of chapter 5, the constraints still hold in this model.

The amount of capital which can be invested will still be limited. The price is fluctuating, but the amount of capital which can be invested is a fixed number. Therefore, the amount of products which can be produced/bought for the amount of money will differ according to the price.

\[
\sum_{t=1}^{3} \sum_{i=1}^{5} \sum_{j=1}^{3} u_{i,j}(t) \ast \tilde{P}_{i,j}(t) < C_{\text{pl max}}
\]

### 7.2. Solving the model

Optimization problems in the real world almost always include parameters which are uncertain when a decision for those parameters should be made. Representing this uncertainty can be done through
two different methodologies. The scenario-based approach and the distribution based approach (Gupta & Maranas, 2003). In the scenario-based approach the uncertainty is described by different scenarios, which can all occur with a certain probability.

All possible outcomes for the price can be represented in a tree. In option pricing, such trees can be solved by backward induction. However, for this problem this will not give the optimal amounts ordered every month. This is due to the maximum amount of inventory. The amount of products produced in December, depends on the January and December price, but November price is not taken into account. However, November and December use the same inventory capacity available for products used in January. With lower prices in November as in December, too many products are ordered in December and the solution not found is not optimal. The amounts ordered depend on the amounts which are ordered in the previous months.

A proof of concept will now be given for solving this type of problem. A tree is constructed with the possible prices. Since the price change follows a normal distribution an interval around every price is taken to calculate the probability that the Chemical X price will take that certain price. The chance that the normal distribution takes a specific value is equal to 0, so therefore the interval is taken. The probability of observing an single value is equal to 0, because the number of values which a continuous distribution can take is infinite. The smaller the interval is set, the more nodes the price tree will have and the closer it gets to a continuous distribution. In our example the price can take 3 values every month. The value of a node is the value of the previous node plus a number generated from the normal distribution of the price change of that month.

In the simplified version every month the company can order 0, 5, 10, 15, 20, 25, 30, 35 or 40 units every month. For every possible combination, the outcomes of the whole tree are calculated. There are $9^3$ ordering combinations possible. A restriction is also placed on the total amount ordered in first 3 periods as a maximum inventory constraint. The total amount ordered in the first three periods cannot be bigger than 80 units. This will reduce the number of possible ordering combinations to 609. So the total costs for every branch of the tree are calculated 609 times.

The optimal solutions are the inventory levels which give the lowest average costs for all nodes. The average costs are a weighted average of the outcome of all end nodes of the tree. The weighted average is based on the chance that the price will end up at that specific end node. An end node which is has a higher probability that the actual price will end on that node, weighs heavier in the average as an end node which is reached with a low probability with higher chance has bigger influence on average.

7.3. Results

The results of simplified model describe in the previous paragraph are presented in this chapter. These results will be used to demonstrate the feasibility using the above described method for solving the dynamic problem. Since this is chapter presents a proof of concept and not a full model, the results are not complete and to be used at The Chemical Company, further research needs to be done.
The preliminary results show that it is optimal to order in November and December until the inventory is filled up, which is 80 units in this case. In the top of the tree it is optimal to order in October and November, but in the rest of the tree the company gains more money by ordering in December and November. Even in the lowest path of the price tree products are ordered upfront. There is no end node where no products are ordered in the first 3 months.

The average CIR is 12.5% over all branches. The branch with the lowest CIR still has a CIR of 8.9% and the highest CIR is 16.5%. The CIR is biased downwards by only doing 4 months compared to the LP model. The price is expected to go up until March. Storing it until March will increase the CIR. The savings will be on average 6.2% on the total costs, with a minimum of 4.5% and maximum of 8%. This measure is higher compared to the LP model, since products are bought only for 1 month. This means the percentage of the total demand which can be bought upfront is bigger. Fewer products need to be bought in the months itself, which results in a higher percentage of the costs saved.

7.4. Conclusions
Due to the simplifications in the dynamic model no comparison can be made between the LP model and the dynamic model. However, the concept presented in this chapter can be developed into a full model. This will lead to results which will give a more realistic insight on the return building stock gives. The chance that the price takes exactly the price of the LP model is very small. When optimizing on multiple prices paths, the chances the actual price lies around those prices increases.

However, the concept presented will lead to a huge amount of paths which need to be calculated. The tree solved in the example had only tree branches, but when doing real calculations at least 10 or more branches are needed per node for more precision. In a 6 period model this makes there will be at least 1 million paths. On top of that the amounts which can be ordered are not limited to multiplications of 5, which will increase the number of situation which needs to be calculated even more. It is feasible to solve the dynamic model with the concept described in this chapter. However, it will lead to a problem which will need a big amount of computational power to be solved.

8. Conclusions, Future research & Recommendations
In this chapter the main findings of this thesis are presented. The main question which is answered in this thesis is: “What are the optimal inventory levels for a chemical product and its derivatives in a divergent, multi-echelon supply chain with seasonal prices?” This was done for Chemical X and its derivatives and in the scope of the project were all storage locations in the EMEA regions.

8.1. Conclusions
Based on the chemical prices of the last years a clear seasonal trend can be found, see Figure 5 and Figure 6. In the first quarter a clear positive trend can be seen in the prices, which means the prices are expected to go up. After the first quarter the positive trend stops and it becomes less clear what is going to happen. On average the price will go down in the second and third quarter of the year. However, the upper bound of the price changes is positive, which means there is also a fair chance that price will go up instead of down. In the fourth quarter prices are relative stable.

Optimizing the inventory to this seasonal trend will have a positive effect on the cash flow and operating income of the chemical company. Optimizing the procurement of Chemical X and its derivatives based on the seasonality is expected to give a CIR of 10% or more when optimizing
from Q4 to Q1 and Q1 to Q2. However, when the inventory is optimized in Q4 for Q1, the return from the optimization of Q1 to Q2 is very low. Optimizing from Q4 to Q1 has a higher expected return as the optimization a quarter later. Therefore it is optimal to build stock in Q4 for Q1. When building stock in the fourth quarter, it is preferable to buy in November. The price is expected to be the lowest in that month and adding the holding costs for 1 month to the price will still give lower costs as buying in December. Buying in December will be done as a second choice when not all restrictions are reached in November. If it is optimal and possible to build more stock in quarter 4 then it is possible to buy and procure in November and December, products will be bought or produced in October which can be used in quarter 1.

The three products which will give a high CIR are Chemical X, product A and product F. Chemical X has the highest return and has by far the most storage capacity which can be used for building stock. Product A has a higher expected return, but the storage capacity is smaller compared to product F. Therefore the net savings will be bigger with product F, but will require a more capital to build stock.

To summarize, The Chemical Company is expected to make the profit when it uses capital to build stock in quarter 4 to be used in quarter 1. Depending on the amount of capital available, it is favorable to use it first for building stock of Chemical X, the next favorable product to build stock for is product A. The third product which is a good choice to be used for building is product F. The other products considered in this thesis have a too low return or the effect on the total gain is negligible due to low amount by which inventory can be adjusted.

8.2. Recommendations & future research

The Chemical Company is trying to reduce the working capital. By doing so recourses are freed up we can be used to be invested in growth. The focus of the company is now on reducing the working capital coming from inventory. However, for Chemical X it is optimal to build stock at the end of the year. This will increase the cash flow and operating income. Lowering the working capital will give you a small cash flow gain in the cash flow when the year report is made, but buying chemical X (derivatives) upfront will improve the cash flow. The focus for most products is now still on reducing the working capital coming from inventory, with the end of year target as the main instrument to reduce inventory. As Figure 4 shows, the prices of some petrochemicals are closely related. Therefore, it can be valuable for The Chemical Company to conduct further research if optimization according to price fluctuations can generate value for the company.

An extension to this research is to investigate the impact of having a second moment where orders can be placed. When the demand is bigger than the units ordered, extra orders can be placed at a higher price. First, the analysis is conducted as in chapter 5. When a better estimate of the price and demand can be made, the business managers can decide to order more products. This is more in line with the real situation. An aggregate planning will be made months upfront. However, when the operational planning is done, there is still the option to buy/produce more products. The raw material costs function will look like:

\[ u_t(t) \cdot P_t(t) + [D_t(t) - u_t(t)]^+ \cdot P_{t,t}(t) \]  \hspace{1cm} (22)

The first part of equation 22 gives the price when you order at first moments. When you see that the demand is higher, you place more orders and price \( P_{t,t}(t) \). This price will be higher, but the chance you end up with a lot of stock due to a wrong demand forecast is smaller.
Another extension can be the option to include the optimization including storage assets. For some products the storage capacity is more than needed for normal operations. Several studies are run to optimize the tank sizes according the demand, but the gains that come from having more inventory space to adjust to seasonal fluctuating prices are not taken into account. Optimizing the costs while taking the gains from reducing the inventory space into account, can be a useful extension.

The dynamic model in this thesis is presented as a proof-of-concept. Developing this concept into a full model can give valuable information of the inventory levels when prices are not predicted perfectly. Assuming that the prices are predicted perfectly will give results which are biased upwards. Taking the uncertainty into account will give insight what the effect on profit and return will be when the price will not take the expected future values.
9. Bibliography


Appendix A: Flowchart Chemical X

Flowchart Product A
Appendix B: CIR and savings per Quarter

### Q1 – Q2

<table>
<thead>
<tr>
<th>CIR</th>
<th>Av</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>12,60%</td>
<td>10,30%</td>
<td>12,20%</td>
</tr>
<tr>
<td>2011</td>
<td>9,70%</td>
<td>9,10%</td>
<td>7,70%</td>
</tr>
<tr>
<td>2012</td>
<td>23,10%</td>
<td>21,70%</td>
<td>6,90%</td>
</tr>
<tr>
<td>2013</td>
<td>1,40%</td>
<td>1,00%</td>
<td>-6,70%</td>
</tr>
</tbody>
</table>

Table 8: CIR Q1-Q2

<table>
<thead>
<tr>
<th>Cost savings</th>
<th>Ave</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>0,82%</td>
<td>0,76%</td>
<td>1,02%</td>
</tr>
<tr>
<td>2011</td>
<td>0,63%</td>
<td>0,61%</td>
<td>0,68%</td>
</tr>
<tr>
<td>2012</td>
<td>1,56%</td>
<td>1,48%</td>
<td>0,65%</td>
</tr>
<tr>
<td>2013</td>
<td>0,10%</td>
<td>0,07%</td>
<td>-0,64%</td>
</tr>
</tbody>
</table>

Table 9: Cost savings Q1-Q2

### Q3-Q4

<table>
<thead>
<tr>
<th>CIR</th>
<th>Av</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>-</td>
<td>-</td>
<td>8,20%</td>
</tr>
<tr>
<td>2010</td>
<td>-</td>
<td>-</td>
<td>1,20%</td>
</tr>
<tr>
<td>2011</td>
<td>-</td>
<td>-</td>
<td>-14,90%</td>
</tr>
<tr>
<td>2012</td>
<td>-</td>
<td>-</td>
<td>10,30%</td>
</tr>
</tbody>
</table>

Table 12: CIR Q3-Q4

<table>
<thead>
<tr>
<th>Cost savings</th>
<th>Ave</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>0,09%</td>
<td>0,18%</td>
<td>0,65%</td>
</tr>
<tr>
<td>2010</td>
<td>0,25%</td>
<td>-0,11%</td>
<td>0,10%</td>
</tr>
<tr>
<td>2011</td>
<td>-0,30%</td>
<td>0,13%</td>
<td>-1,36%</td>
</tr>
<tr>
<td>2012</td>
<td>-0,01%</td>
<td>0,14%</td>
<td>0,77%</td>
</tr>
</tbody>
</table>

Table 13: Cost savings Q3-Q4

No extra inventory bought/produced in Q3.

### Q2-Q3

<table>
<thead>
<tr>
<th>CIR</th>
<th>Av</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>-</td>
<td>-</td>
<td>11,00%</td>
</tr>
<tr>
<td>2011</td>
<td>-</td>
<td>-</td>
<td>-20,5%</td>
</tr>
<tr>
<td>2012</td>
<td>-</td>
<td>-</td>
<td>3,70%</td>
</tr>
<tr>
<td>2013</td>
<td>-</td>
<td>-</td>
<td>0,37%</td>
</tr>
</tbody>
</table>

Table 10: CIR Q2-Q3

<table>
<thead>
<tr>
<th>Cost savings</th>
<th>Ave</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>0,09%</td>
<td>0,18%</td>
<td>0,65%</td>
</tr>
<tr>
<td>2011</td>
<td>0,16%</td>
<td>0,16%</td>
<td>0,10%</td>
</tr>
<tr>
<td>2012</td>
<td>-0,58%</td>
<td>-0,58%</td>
<td>-1,36%</td>
</tr>
<tr>
<td>2013</td>
<td>-0,14%</td>
<td>-0,14%</td>
<td>0,77%</td>
</tr>
</tbody>
</table>

Table 11: Cost savings Q2-Q3

Savings due to optimized procurement/production in Q3

### Q4 – Q1

<table>
<thead>
<tr>
<th>CIR</th>
<th>Ave</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>20,7%</td>
<td>13,4%</td>
<td>29,2%</td>
</tr>
<tr>
<td>2010-2011</td>
<td>18,6%</td>
<td>14,8%</td>
<td>20,9%</td>
</tr>
<tr>
<td>2011-2012</td>
<td>25,2%</td>
<td>21,7%</td>
<td>23,7%</td>
</tr>
<tr>
<td>2012-2013</td>
<td>7,0%</td>
<td>6,9%</td>
<td>5,5%</td>
</tr>
</tbody>
</table>

Table 14: CIR Q4-Q1

<table>
<thead>
<tr>
<th>Cost savings</th>
<th>Ave</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-Forecast</td>
<td>2,0%</td>
<td>1,3%</td>
<td>2,8%</td>
</tr>
<tr>
<td>2010-2011</td>
<td>1,9%</td>
<td>1,1%</td>
<td>2,8%</td>
</tr>
<tr>
<td>2011-2012</td>
<td>3,2%</td>
<td>2,1%</td>
<td>2,4%</td>
</tr>
<tr>
<td>2012-2013</td>
<td>0,8%</td>
<td>0,8%</td>
<td>0,5%</td>
</tr>
</tbody>
</table>

Table 15: Cost savings Q4-Q1

No extra inventory bought/produced in Q4.

Savings due to optimized procurement/production in Q4
Appendix C: Poster

Optimizing aggregate inventory levels when prices fluctuate seasonally
A case study in the Chemical Industry

Introduction
The economic downturn following the financial crisis increased the pressure on the profits of chemical producers. To remain competitive in these difficult economic times, companies run programs to decrease their costs. The Chemical company tries to reduce the input costs for processes. In this research the raw material costs are being optimized by finding the best timing to produce and procure products.

Price seasonality
The price of the chemical investigated in this research, Chemical X, fluctuates seasonally. Figure 1 shows the average month-to-month price change. A positive value for month 1 means the price is expected to go up from December to January. Figure 1 shows that the price is expected to go up in the first quarter of the year. In quarter 2 and beginning of quarter 3 the average price is expected to go down. However the upper limit is positive, except month 5, which means there is also a fair chance the price goes up in second and third quarter.

Mathematical model
To find the optimal ordering policy an linear programming model is developed. The aim of the model is to minimize the total costs of raw materials plus the holding costs. The model will be used for the strategic aggregate planning of the desired inventory levels for the following quarter. To see how the optimized model performs compared to the current situation, both situations need to be defined:

- Current situation: Buy/produce exactly for the demand which is forecasted for that month, the inventory level is kept at the same level as at the beginning of the quarter.
- Optimized situation: Buy/produce the optimal amounts of products according to the seasonal price changes. Look one quarter ahead to see if it is favorable to buy/produce more for the next quarter.

Results
Optimizing the inventory according to the seasonal price decreases the total costs. Optimizing production and procurements in Q4 for Q1 adds the most value to the company. Doing the analysis with prices of the last 3 years it can be seen that the costs will go down, see table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1-Q2</th>
<th>Q2-Q3</th>
<th>Q3-Q4</th>
<th>Q4-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>15.6%</td>
<td>-</td>
<td>-</td>
<td>20.7%</td>
</tr>
<tr>
<td>2012</td>
<td>9.7%</td>
<td>-</td>
<td>-</td>
<td>18.4%</td>
</tr>
<tr>
<td>2011</td>
<td>13.1%</td>
<td>-</td>
<td>-</td>
<td>25.1%</td>
</tr>
<tr>
<td>2010</td>
<td>14.0%</td>
<td>-</td>
<td>-</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

Table 1: Forecasted capital investment return

The Chemical industry is a capital intensive industry. Therefore it is important to see, what the return is when extra capital is needed to procure products earlier. Table 1 shows that The Chemical Company has good returns when it buys products in Q1 for Q2 and when it buys in Q4 for Q1. However optimizing in Q4, the return of Q1-Q2 decreases a lot. Looking at the returns that would have been made with the prices of the last 3 years, optimizing in Q4 for Q1 adds value to the company.

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1-Q2</th>
<th>Q2-Q3</th>
<th>Q3-Q4</th>
<th>Q4-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0.92%</td>
<td>0.06%</td>
<td>0.18%</td>
<td>2.0%</td>
</tr>
<tr>
<td>2012</td>
<td>0.65%</td>
<td>0.10%</td>
<td>0.13%</td>
<td>1.9%</td>
</tr>
<tr>
<td>2011</td>
<td>0.56%</td>
<td>0.58%</td>
<td>0.13%</td>
<td>1.2%</td>
</tr>
<tr>
<td>2010</td>
<td>0.10%</td>
<td>-0.14%</td>
<td>0.14%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

Table 2: Forecasted capital investment return

Due to the seasonality of Chemical X, prices of the products which have Chemical X as their main ingredient, Chemical X derivatives, also fluctuate seasonal. Therefore the flow of Chemical X through the company was modelled, to find all products which contain Chemical X. From those derivatives, the 4 most promising ones were taken to see what the effect was of optimizing the inventory according to the price seasonality of Chemical X.