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(Siemens AG Urban Transport, Vienna)"

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AGENDA

LIST OF TABLES III

LIST OF FIGURES IV

LIST OF FORMULAS V

LIST OF ABBREVIATIONS VI

ACKNOWLEDGEMENT VIII

1 INTRODUCTION 1

1.1 SIEMENS AG 2

1.1.1 Siemens AG Mobility 3

1.1.2 Urban Transport in Vienna 3

1.3 PROBLEM STATEMENT 4

1.4 STATUS QUO 5

1.5 OBJECTIVE 7

2 TRADITIONAL SUPPLY CHAIN 8

2.1 SUPPLY CHAIN COORDINATION 8

3 IT-SUPPORTED PROCUREMENT LOGISTIC CONCEPTS 11

3.1 COLLABORATIVE PLANNING, FORECASTING AND REPLENISHMENT 12

3.1.1 Vendor Managed Inventory 13

3.1.2 Contract Warehouse Concept 18

3.1.3 Consignment Warehouse Concept 21

3.1.4 Realistic implementation at Plant Vienna 21

3.2 COLLABORATIVE PROCUREMENT CONVERSION EFFECTS 23

4 DETERMINATION OF POTENTIAL SUPPLIERS 25

5 OPTIMAL MINIMUM AND MAXIMUM STOCK 27

5.1 WAREHOUSE TYPES AND STORAGE AREA AT PLANT VIENNA 27

5.2 DATA COLLECTION 28

5.3 THE NEWSVENDOR MODEL 29

5.4 AVERAGE DEMAND AND DEVIATION FOR EACH PROJECT 31

5.5 ORDER-UP-TO INVENTORY MODEL 33

5.5.1 Service Level Alpha 36

5.5.2 Service Level Beta 40

5.6 Service Level Results 41
5.7 Linear Programming Model 42
5.8 Result 44
6 DELIVERY COMBINATION 47
6.1 Deliveries to Plant Vienna 47
6.2 Data Collection 49
6.3 Vehicle Routing Problem 50
6.3.1 Direct Shipments with Milk Runs 53
6.3.2 Saving Algorithm 54
6.4 Implementation 56
6.5 Result 60
7 CONCLUSION 63
8 BIBLIOGRAPHY 65
9 APPENDIX I
9.1 Results Part II I
9.2 Abstract English IX
9.3 Abstract German IX

List of Tables

TABLE 1: VMI ADVANTAGES AND DISADVANTAGES FOR THE CUSTOMER. SOURCE: OWN TABLE BASED ON (HIRZEL, GEISER, & GAIDA, 2013) AND (MELZER-RIDINER, 2004) 17

TABLE 2: ADVANTAGES AND DISADVANTAGES FOR THE SUPPLIER. SOURCE: OWN TABLE BASED ON (HIRZEL, GEISER, & GAIDA, 2013) AND (MELZER-RIDINER, 2004). 17

TABLE 3: ADVANTAGES AND DISADVANTAGES FOR BOTH PARTIES. SOURCE: OWN TABLE BASED ON (HIRZEL, GEISER, & GAIDA, 2013) AND (MELZER-RIDINER, 2004). 18

TABLE 4: ADVANTAGES AND DISADVANTAGES OF CONTRACT WAREHOUSE FOR THE CUSTOMER. SOURCE: OWN TABLE BASED ON (STOLLENWERK, 2016) AND (KOCH, 2012) 20

TABLE 5: ADVANTAGES AND DISADVANTAGES OF CONTRACT WAREHOUSE FOR THE SUPPLIER. SOURCE: OWN TABLE BASED ON (STOLLENWERK, 2016) AND (KOCH, 2012). 20

TABLE 6:ADVANTAGES AND DISADVANTAGES OF CONTRACT WAREHOUSE FOR CUSTOMER AND SUPPLIER. SOURCE: OWN TABLE BASED ON (STOLLENWERK, 2016) AND (KOCH, 2012). 20

TABLE 7: STORAGE AREAS AT PLANT VIENNA. 27

TABLE 8: DATA COLLECTION 29

TABLE 9: PROJECT OVERVIEW. 32

TABLE 10: MINIMUM AND MAXIMUM INVENTORY LEVEL PER MONTH IN CARS, SQUARE METERS AND HOLDING COSTS, PROJECT 4 38

TABLE 11: MINIMUM AND MAXIMUM INVENTORY LEVEL PER MONTH IN CARS, SQUARE METERS AND HOLDING COSTS FOR WAREHOUSE TYPE A2, PROJECT 4. 38

TABLE 12: MINIMUM AND MAXIMUM INVENTORY LEVEL PER MONTH IN CARS, SQUARE METERS AND HOLDING COSTS FOR WAREHOUSE TYPE B1, PROJECT 4. 39

TABLE 13: MINIMUM AND MAXIMUM INVENTORY LEVEL PER MONTH IN CARS, SQUARE METERS AND HOLDING COSTS FOR WAREHOUSE TYPE B2, PROJECT 4. 39

TABLE 14: TOTAL REQUIRED MINIMUM AND MAXIMUM INVENTORY SPACE FOR α = 0.85. 39

TABLE 15: TOTAL REQUIRED MINIMUM AND MAXIMUM INVENTORY SPACE FOR α = 0.99. 40

TABLE 16: TOTAL REQUIRED MINIMUM AND MAXIMUM INVENTORY SPACE FOR $\beta = 0.85$. 41

TABLE 17: TOTAL REQUIRED MINIMUM AND MAXIMUM INVENTORY SPACE FOR $\beta = 0.99$. 41

TABLE 18: REDUCED DATA FOR IMPLEMENTATION. 49

TABLE 19: LONGITUDE AND LATITUDE FOR MAPPOINT 2013. 50

TABLE 20: DELIVERIES WEEK 2 NOVEMBER. 57

TABLE 21: RESULTS WEEK 2 NOVEMBER. 59

TABLE 22: RESULTS ALL WEEKS. 60

List of figures

Figure 1: Overview Standard Procurement Models. Source: (Siemens AG, 2013), (Potthast, Gärtner, & Hertrampf, 2012)........ 6
Figure 2: Lack of Coordination impacts. Source: Own figure based on (Chopra & Meindl, 2016)........ 9
Figure 3: Process of VMI based procurement. Source: Own figure based on (Rüger, 2004). 15
Figure 4: Contract Warehouse without logistics service provider. Source: Own table based on (Koch, 2012)........ 19
Figure 5: Conversion changes of collaborative procurement. Source: Own figure based on (Witthaut, 2015)........ 23
Figure 6: Production Plan Histogram. Source: Own figure based on production plan of project 4 32
Figure 7: Order Cycle. Source: Own figure based on (Thonemann, 2010). 34
Figure 8: Location Map potential VMI suppliers and Plant Vienna. Source: Google Maps. 48
Figure 9: Route example........ 51
Figure 10: Direct Shipment with Milk Runs. Source: Own figure based on (Chopra & Meindl, 2016). 53
Figure 11: Clarke and Wright Saving Algorithm. Source: Own figure based on (Lysgaard, 1997). 54
Figure 12: Siemens Saving Algorithm........ 55
Figure 13: Routes week 2 November. Source: Own figure based on Google Maps. 61

Es konnten keine Einträge für ein Abbildungsverzeichnis gefunden werden.

List of formulas

FORMULA 1: CALCULATION OF THE Z – STATISTIC 30

FORMULA 2: OPTIMAL ORDER QUANTITY 31

FORMULA 3: ORDER QUANTITY 34

FORMULA 4: OPTIMAL TARGET STOCK 35

FORMULA 5: SAFETY STOCK 35

FORMULA 6: CRITICAL RATIO 36

FORMULA 7: CALCULATION OF Z - STATISTIC FOR SERVICE LEVEL BETA 40

FORMULA 8: LP MODEL FOR MAXIMUM STOCK 43

FORMULA 9: LP MODEL FOR THE CVRP. SOURCE: (TOTH & VIGO, 2002, P.12). 52

List of abbreviations

AG: Aktien Gesellschaft/ Stock Company

C_o: Overage Costs

CR: Continuous Replenishment

CRP: Continuous Replenishment Program

CRS: Continuous Replenishment System

CPFR: Collaborative Planning, Forecasting and Replenishment

C_u: Underage Costs

CW: Contract Warehouse

D_a: Total Transportation Costs in case a

DAP: Delivered At Place

EDI: Electronic Data Interchange

EOQ: Economic Order Quantity

ERP: Enterprise-Resource-Planning-System

FCA: Free Carrier

h: Holding Costs

ICT: Information and Communication Technology

JIS: Just-In-Sequence

JIT: Just-In-Time

LP: Linear Programming

μ: Mean

NCC: Non-Conformance Costs

NRC: Non-Recurring Costs

PVO: Purchasing Volume

q: Quantity

Q:* Optimal Order Quantity

R:* Reorder Point

s: Reorder level

S: Minimum Stock

S^*: ……………………………………………………………..…... Maximum/Target Stock

SCOR: ..……………………………………….... Supply-Chain-Operations-Reference-Model

σ: ……………………..………………………………………………… Standard Deviation

s_{ij}: ……………………………………………………………………….. Saving from node i to j

SMI: ..………………………………….....…………………… Supplier Managed Inventory

t: ……..…………………………………………………………………...……. Ordering Cycle

TCO: ..……………………………………………………………...……Total Cost of Ownership

VMI: ..…………………………………………….……………… Vendor Managed Inventory

XML: ..……………………………………………………………. Extensible-Markup-Language

X_t: ………………………………………………..……………………… Order Quantity at t

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1 Introduction

In 2017, more than half of the world's population lives in cities. Increasing urbanization requires smarter and efficient infrastructure solutions. Not only are dynamic urbanization processes extremely high in emerging countries, but also the term 'rural exodus' is against all odds still present in highly developed areas. Challenge in western regions is to optimize existing structures. In Europe, our lives and our economy is characterized by a steady growth of mobility and acceleration. Mobility is the basis of our economic activities, and represents flexibility, change and transformability. The trend goes to intermodality, switching between transportation modes and 'using' instead of 'owning' is positioning additional innovation towards mobility. Car sharing and E-Bike concepts complement the 'shared space' next to public transport like busses, trains and cars and bicycles on the streets. As more and more people are moving into cities and cities become megacities and conglomerate into enormous agglomerations, demand in public transport in urban and metropolitan areas is increasing rapidly (Zukunftsinstitut, 2016). A majority of cities in developed areas operate with long-established public transport networks, which nowadays need restructuring and automation. Governments, industry players, media groups, service providers, and other organizations collaborate, reinventing the transport and mobility field (Union Internationale des Transports Publics, 2015).

We find ourselves in the age of digitalization and industry 4.0, where everyone and everything is connected. Information and Communication Technology promote and design a fourth industrial revolution and the vision of so far non-achieved degree of flexibility and productivity in the value-added management. Social and economic trends are striving towards individualization of customer requests. Intelligent production systems provide the opportunity to manufacture little quantity to the costs of serial production. Competition does not longer exist only between companies on the same level, but whole supply chains are a factor of success. Collaborative partnerships between individual players within a supply chain are essential for market leadership. Increasing globalization and the growing flow of information and goods lead to innovative and efficient purchasing concepts in the economy. Autonomous systems, demand oriented production, low inventory stocks and high flexibility decide between success or failure. Manufacturing companies need to concentrate on their core business, production, whereas logistics play a supportive role in this environment (Kleemann & Glas, 2017, p. 5 ff.).

1.1 Siemens AG

Werner Siemens (known as Werner von Siemens after 1888) and Johann Georg Halske founded Siemens AG in Berlin in 1847. Starting with the production of precision-engineering and electrical telegraph systems, Siemens developed from a small workshop into one of the world's largest companies in electrical engineering and electronics.

In 1866, Werner von Siemens discovered the dynamoelectric principle, and driven by Siemens innovations, heavy current engineering began to develop rapidly. Thirteen years later, in 1879, the first electric railway operated at the Berlin Trade Fair.

With identifying market opportunities and technical developments, the company processed advancing. In the 1920s, the product range includes lighting, medical engineering, wireless communication, and household appliances. During the era of National Socialism, Siemens and the rest of the German industry, was draft into the system of war economy, which lead to increasing sales and size of the workforce. To meet its manufacturing targets, forced labor was used.

At the end of World War II, Siemens lost four fifths of its assets. Due to the uncertainty of the political situation in Berlin, the headquarter was relocated to Munich and Erlangen, but the secondary headquarters were retained in Berlin.

In the mid-1960s, Siemens had already regained its former position in the world market and six years later Siemens & Halske AG, Siemens-Schuckertwerke AG and Siemens-Reiniger-Werke AG merged to form Siemens AG. Now, Siemens' main businesses were consolidated into six independently operating groups.

In the age of globalization, the company passed through a structural reformation and 15 smaller business units were created to operate more flexible and in closer proximity to the market. Productivity, innovation and growth constitute the strategic pillars to increase efficiency and effectiveness (Siemens Archives 2007, 2017).

Today, Siemens AG is one of the largest industrial manufacturing companies in the world. The company consists of eight divisions: Building Technologies, Digital Factory, Energy Management, Mobility, Power and Gas, Process Industries and Drives, Wind Power and Renewables as well as Healthcare. In addition, Financial Service serves as a ninth division as a provider for Business-to-Business processes.

In the past fiscal year, Siemens AG employed about 351,000 people worldwide with a total revenue of € 79,644 million. About € 7,825 million were generated in the Mobility division (Siemens AG, 2016, p. 2 ff.). On October 4 2017, Siemens announced the merger of its Mobility Division with Alstom.

1.1.1 Siemens AG Mobility

National economies are confronted with a growing demand for mobility. Transporting people and goods are challenging infrastructures worldwide. Especially, logistics and transport facilities in cities are facing problems of increasing road traffic. The Mobility division provides a comprehensive portfolio, consisting of modern, interconnected, and IT-based mobility, subdivided into five business units: Mobility Management, Turnkey Projects & Electrification, Mainline Transport, Urban Transport and Customer Services.

The business units of Mainline and Urban Transport include the full range of vehicles for rail traffic: regional, intercity, high-speed trains, metro cars, streetcars and light rails, passenger coaches, driverless vehicles and locomotives. Furthermore, the portfolio also includes signal and control technology, electrification technology and turnkey mobility systems to name a few (Siemens AG, 2017).

The global market for rolling stock is characterized by stagnating overcapacities, especially in Europe. Innovative and individual projects are the differentiating characteristics of rolling stock products. The economic environment of project business is volatile, uncertain, complex ambivalent. This leads to price erosion and intensifies aggressive competition. Above all, the global leader CRRC expands its market presence and establishes in Europe. Due to these facts, SAGs Mobility division is situated in unfavorable market conditions. Goals of the merging process with Alstom are an increase in operative stability, reduced costs and complexity, more innovation and an improved competitive position. In that regard, Supply Chain Management should work as a leverage effect for the merging process and the set goals.

1.1.2 Urban Transport in Vienna

One business unit of the Mobility division is Urban Transport, with its head office and plant in Vienna, Austria. The head office of Siemens AG Austria is located in 1210 Vienna, Floridsdorf, whereas the plant of Urban Transport is in 1110 Vienna, Simmering. Trams, metros and further light rails build the product portfolio of Plant Vienna, which can be expanded to mainline vehicles. The facility is about 140,000 square meters with its production area of about 84,000 square meters. The plant was founded in 1852, after it moved from Vienna Leopoldstadt to Vienna Simmering. In 1941, the “Simmering-Graz-Pauker AG” was founded in which Siemens 1992 acquired a share of 26%. Within the next nine years, Siemens increased its share up to 100% in 2001. Three years later the company’s name was changed to “Siemens Transportation Systems Austria” and was finally integrated into the Siemens AG Austria in 2009 (Siemens AG Österreich, 2017). As a response to the global market conditions, Siemens will merge its’ Mobility Business Units of Urban Transport and Mainline Transport with December 1 2017 under the roof of the new Business Unit “Rolling Stock”.

1.3 Problem Statement

Production and manufacturing at Plant Vienna depends on project situation and can vary immensely. A low order situation leads to idle times and affects many jobs at Vienna plant; an overload of simultaneous projects might exceed capacity in manufacturing, assembly, employees and warehouse. The latter is restricted to approximate 16,000 square meters and consists of different types of warehouses. Due to factors related to cost saving, the finance department of Siemens AG Austria decided to close its external warehouse at Siemens AG Austria’s head office in Floridsdorf. The aim is to prevent high capital commitment, and to encourage and increase flow of capital. Inventory planning, order management and manufacturing cycle of current projects are based on an available storage area of additional 6,000 square meters in the external warehouse. Starting from this point, several working groups and task forces are developing different methods and projects to cope with the storage reduction from 22,000 square meters to 16,000 square meters. Delivery concepts, order management and warehouse planning need to be adjusted, and material availability must be guaranteed simultaneously.

Order processes between Siemens AG Austria and suppliers are quite static. Siemens AG Austria bears responsibility for inventory risks and supply reliability. As already mentioned, the rail industry depends on project business. This complicates a stable, constant long-term relationship with suppliers, because order volume can vary widely with time. Processes and activities from ordering by Siemens AG Austria to the actual delivery of the component by the supplier are portrayed in a mostly non-transparent flow of information and material. The supplier receives little information about inventory situation, which leads to a high delivery frequency and consequently results in a high inventory stock. The overall results are high inventory and capital costs, costs for personnel, energy, maintenance and insurance. Additional problems which Plant Vienna is confronted with are low material availability, limited access to material, and a slow material flow.

These facts strongly contrast to the previously mentioned cost-saving measure of closing the external warehouse. The high operating expenses intensify the difficulty with the procurement ordering processes. Delivery and transport managed by Siemens does not allow a bundling of deliveries, which provokes a high number of deliveries and goods receipt processes.

High purchase volume and non-transparent production- and logistics processes leads to a suboptimal determination of the procurement model for each supplier.

1.4 Status Quo

Static order processes and material provisions are standardized by obligatory group-wide procurement models, which you can see in figure 1. Procurement efficiency shall be optimized by a conversion of the procurement logistics processes.

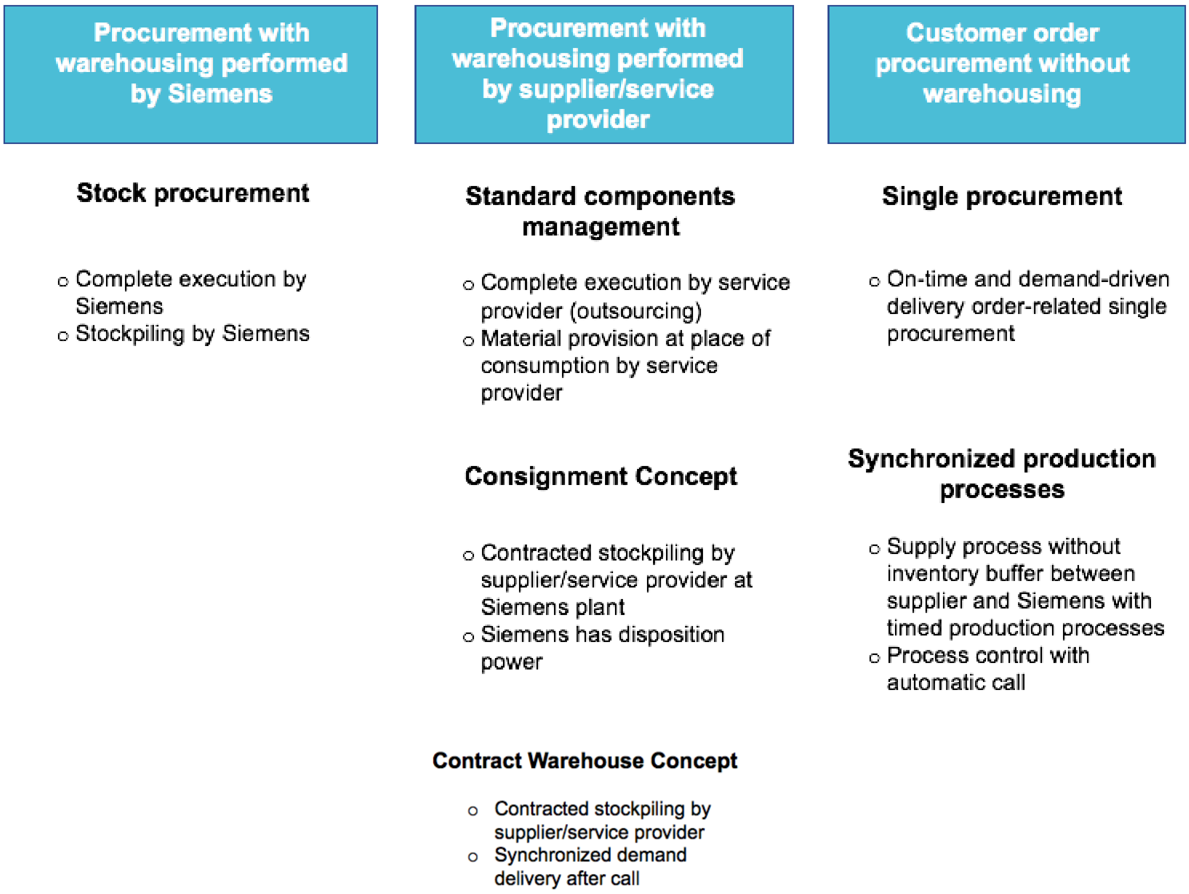

Figure 1: Overview Standard Procurement Models. Source: (Siemens AG, 2013), (Potthast, Gärtner, & Hertrampf, 2012)

The main differences between these procurement models are warehousing and transfer of ownership. Furthermore, aspects like capital commitment costs, required storage and personnel capacity as well as the dependency on forecasts are additional differences. Most procured material at Plant Vienna are not transacted via customer 'order procurement without warehousing' models, therefore 'procurement with warehousing performed by supplier/service provider' are brought to the fore. Whereby Plant Vienna is not cooperating with a service provider, while this opportunity is relevant for Plant Krefeld.

The third procurement model, 'procurement with warehousing performed by Siemens', is the starting point of this master thesis, as this warehousing model shall be replaced by innovative procurement models like 'Consignment Concept' or 'Contract Warehouse Concept'. Here, transfer of inventory responsibility and supply risk, imply a high potential of cost saving for Siemens AG Austria. The underlying execution concept is the 'Vendor Managed Inventory' (VMI) or 'Supplier Managed Inventory' (SMI), where we will use the former term (Koehter, 2010, p. 418).

For Plant Vienna, only ‘Contract Warehouse Concept’ (CW) and, in combination, VMI are relevant, as the ‘Consignment Warehouse Concept’ contradicts to the closed external warehouse and the restricted storage possibilities at Plant Vienna.

1.5 Objective

Based on a previous analysis about potential VMI suppliers for each Siemens AG plant, this master thesis wants to determine the optimal minimum and maximum inventory at Plant Vienna. Potential suppliers for Plant Vienna are nominated by means of three criteria: purchase volume, number of deliveries and delivery reliability. Each of these criteria are calculated and graded for each individual supplier, relevant for Plant Vienna. Data used for this analysis is from the previous fiscal year. The resulting key performance indicator measures whether a supplier is appropriate for the implementation of the VMI concept.

Part one of the underlying master thesis calculates based on the ‘Newsvendor Model’ and the ‘Order-up-to Inventory Model’ the optimal minimum and maximum inventory for each nominated supplier and its products. Additionally, the required storage area and storage costs are calculated. Both outcomes consider each supplier, for each current project, material and storage type at Plant Vienna.

The second part tries to improve deliveries of the suppliers considered in part one. With the theory of ‘Direct Shipping with Milk-Runs’ and the ‘Clark and Wright Saving Algorithm’, the VMI based deliveries controlled by the suppliers, shall be bundled and combined and lead to transport cost savings. The underlying implementation was made in C++.

2 Traditional Supply Chain

A supply chain is a system consisting of material supplies, production facilities, distribution services and customers. All these parties are linked together in a downstream feed-forward flow of materials (deliveries) and the upstream feedback flow of information (orders).
In a traditional supply chain, each company is responsible for its own inventory control, production and distribution activities. The main problem within a traditional supply chain is uncertain demand and therefore the required quantity to order. This classic production and inventory problem tries to transform incomplete information about the market place into co-ordinated plans for production and replenishment via a production or inventory control system. In this case, each firm in the traditional supply chain bases its production or delivery orders solely on its immediate customer sales and inventory levels. There is no overarching information about the end customers demand or production and inventory capability downstream the supply chain.
The missing visibility of overall demand at each stage of the supply chain can and does cause several problems (Disney & Towill, 2003, p. 199 ff.).

2.1 Supply Chain Coordination

An effective and efficient supply chain from retailer over distributor to raw material supplier needs coordination. The overall supply chain performance depends on decisions and actions by all players in the supply chain. Although every party supports the objective of optimizing the supply chain performance, each party's predominant objective is the optimization of its own performance. Self-serving behavior of each firm of the supply chain can lead to a decrease in the overall supply chain performance (Cachon & Terwiesch, 2013, p. 373).
Supply chain coordination improves if all involved parties take actions and share information. Lack of coordination might occur when different stages of the supply chain have conflicting objectives or when information is delayed or distorted. Due to missing coordination, demand variability tends to increase moving up the supply chain. The so-called bullwhip effect is problematic for effective operations and affects many costs in a supply chain. Fluctuations in orders increase as one moves upstream the supply chain. Companies face demand from distribution centers that are much more variable than customer demand. The bullwhip effect can lead to increased inventories, less product availability, and a decrease in profit (Chopra & Meindl, 2016, p. 260 f.).

A lack in coordination tends to hurt both responsiveness and cost in a supply chain as product availability gets more expensive when providing a given level of product availability (Chopra & Meindl, 2016, p. 262 f.).
The impact of the lack of coordination on a supply chain performance are illustrated in figure below.

Figure 2: Lack of Coordination impacts. Source: Own figure based on (Chopra & Meindl, 2016)

To prevent a lack of coordination in the supply chain, Siemens AG Austria's Supply Chain is based on the 'Supply-Chain-Operations-Reference-Model' (SCOR-Model). This model was developed to describe and record all business activities, which are related to the fulfilment of customer requirements (Lawrenz, Hildebrand, & Nenninger, 2001, p. 109). The basic SCOR-Model is a product of the 'Supply Chain Council', a global, independent, non-profit-organization. One of the most important innovations of the SCOR-Model is the structure of three process types; planning, execution, enable. The hierarchical structure consists of three to four levels, which strive for different targets. Level one to three are prescribed in the SCOR-Model, whereas the user can define level four. The first level describes the scope of the Supply Chain by explaining the processes of plan, source, make and deliver. Level II defines the core processes in the supply chain and combines process chains. The third level provides information for the second level (Lawrenz, Hildebrand, & Nenninger, 2001, p. 119 f.). Siemens AG Austria uses an extended version of the SCOR-Model, specialized in the project-based business environment. With its multidimensional character and the interconnectivity of the stages, Siemens AG Austria expects complete information and material flow, consistency and smooth production from the use of the SCOR-Model.

3 IT-supported procurement logistic concepts

Procurement logistics deals with the provision of non-self-produced goods or services of a company. It is an elementary part of logistical supply chains, next to production, distribution and disposal logistics. The aim is to purchase these non-self-produced goods or services on conditions that optimize the overall supply chain. Therefore, the procurement logistics shall not be considered isolated, but needs to be matched with downstream processes of production and distribution logistics. Procurement logistics' responsibility is to plan, implement and control all material and information flows of the company and the supplier, with the objective to guarantee demand-driven supply (Koehter, 2010, 407 ff). Besides availability guarantee of external procured goods or services, the cost optimization, regarding time and quantity, needs to be considered. At this, it is focused on the 'Total Cost of Ownership' (TCO) of the procurement logistic costs. Processes of procurement must be arranged in the most efficient and effective ways, concerning incurred costs. Thereby, aspects like quality improvement, system flexibility and customer orientation are prioritized (Klaus, Krieger, & Krupp, 2012, p. 63).

Within the procurement logistics, one significant cost driver is high inventory of material in the warehouse, which the company stocks until demanded and provisioned for production. High inventory and capital commitment costs can arise, depending on the value, properties, and characteristics and quantity of the goods. To minimize these costs, 'Information and Communication Technologies' (ICT) are used, starting from the ordering to the delivery and warehousing of goods or services to the overall business process. The coordination of material flow with simultaneous control of information flow is an integral part of the IT-supported procurement optimization, between manufacturer and supplier (Hausladen, 2016, p. 85 ff.).

Common models of warehousing and order policy are related to two parameters to ensure delivery capability: ordering cycle t and order quantity q. In case order cycle t is fixed, ordering of the material is automatically triggered within a fixed period. If order cycle t is variable, ordering time depends on a predefined event, in general when stock drops below a reorder level s. In case order quantity q is fixed, the quantity ordered are of the same batch size, regardless of the order cycle. With a variable order quantity q, the quantity ordered is chosen to reach a target or a maximum stock S, when the material is delivered (Melzer-Ridiner, 2004, p. 91). The useful combination of these parameters leads to inventory driven disposition of order point system (s, q – policy; s,S – policy) and ordering schedule system (t,q – policy; t, S – policy) (Klaus, Krieger, & Krupp, 2012, p. 69). These strategies are based on stochastic order planning. Here, material demand and is uncertain or unknown and the calculation of order quantity and order point needs to be considered separately. If, however, material demand is certain before ordering, order planning is deterministic and disposition operates demand driven. Key instrument to calculate the optimal quantity ordered, with respect to arising expenses during the planning period, is the 'Economic Order Quantity' (EOQ) (Chopra & Meindl, 2016, p. 287).

In both cases of order planning, the manufacturing company is responsible for warehousing and supply guarantee. Siemens AG Austria, as well as Siemens AG in Germany, strives for a switch in responsibility towards the supplier. Three integrative procurement models – VMI, CW and 'Consignment Warehouse Concept', are presented, which are of interest for Siemens AG and Siemens AG Austria. For the latter, the emphasis will be put on VMI and (in combination) CW. Nevertheless, a 'Consignment Warehouse Concept' will be introduced, as it is relevant for Siemens AG in Krefeld. These models are detached from the common ordering models and are based on an integrated information and communication system between Siemens and its suppliers.

3.1 Collaborative Planning, Forecasting and Replenishment

Coordination is the basis for an effective and efficient supply chain as already discussed in chapter 2.1. Once the obstacles to coordination are identified, several actions can overcome these obstacles and achieve coordination in the overall supply chain. For example, aligning goals and incentives, or designing pricing strategies (Chopra & Meindl, 2016, p. 268 f.). Improving information visibility and accuracy with building strategic partnerships as well as trust between two or more business partners are actions Siemens AG Austria focuses on, based on the current situation of Plant Vienna. With the help of Vendor Managed Inventory and the Contract Warehouse Concept, Siemens AG Austria wants to improve its operational performance. Both of these procurement models, implemented independently or in combination, form a basis for a collaborative planning, forecasting and replenishment strategy to improve coordination and overcome restricted warehouse space at Plant Vienna.

Collaborative procurement models can be classified within the context of 'Collaborative Planning, Forecasting and Replenishment' (CPFR). Here, the procurement procedure includes all involved parties with different responsibility. The supplier takes responsibility for the contractual agreed inventory stock of its material, whether the warehouse is located at the suppliers or the customer's side. The customer takes responsibility for accurate information about the inventory level and demand forecast, which improves production planning for the supplier. Particular emphasis is placed on information visibility and trust between both parties (Chopra & Meindl, 2016, p. 272).

Assigning responsibility across the supply chain to a single entity ensures visibility and a common forecast stabilizes orders across the supply chain. Common industry practices of a single responsibility assignment are 'Continuous Replenishment Programs' (CRP) and VMI. The former includes a wholesaler or manufacturer, who replenishes on a regular 'Point of Sale' (POS) data or actual withdrawals of inventory from the customer's warehouse. For this, IT systems are used that are linked across the supply chain to provide a good information infrastructure (Chopra & Meindl, 2016, p. 273).

Based on the idea of CRP, Siemens AG Austria established VMI and the CW concept. Both will be discussed in detail. For Siemens AG in Germany, especially Plant Krefeld, the 'Consignment Warehouse Concept' is also relevant, but is not discussed in detail in this thesis.

Aim of both, CRP and VMI, is to reduce the inventory level on both sides with real-time supply and decrease operative costs of procurement (Klaus, Krieger, & Krupp, 2012, p. 112 f.).

3.1.1 Vendor Managed Inventory

The concept of 'Vendor Managed Inventory' is based on a demand driven supply of goods and services. With VMI, the supplier is responsible for all decisions regarding product inventories at the customer's warehouse, here Siemens AG Austria Plant Vienna. Control of replenishment decisions moves from the manufacturer to the supplier (Chopra & Meindl, 2016, p. 273). Via ICT, the supplier gets access to the inventory stock and is responsible to keep the material stock between predefined minimum and maximum quantities. Primary objective is to ensure a high material availability and at the same time, the reduction of capital commitment and storage costs for the manufacturing company. This helps to improve the supplying companies forecast and better match manufacturer production with customer demand. VMI can lead to a profit increase for the manufacturer and thus increasing profits for the entire supply chain (ibid.).

Many firms have already implemented their own model of VMI, but the main aspects remain constant. First, the customer does no longer decide when and how much goods or services to order. Instead, the supplier is the decision maker for timing and quantity of shipments to the customer. Both parties mutually agree on an objective that the supplier uses to guide replenishment decision, in general a safety stock as the minimum quantity and a target in stock as the maximum quantity of the material. Second, as the supplier is responsible for replenishment decision, the supplier needs information in form of data, which is input to an automatic replenishment system. Those computer programs support the decision about the timing and quantity of replenishment for each product transacted with VMI. Here, the supplier must be informed about potential demand shifts that can be anticipated. The computer programs are often referred to as 'Continuous Replenishment Systems' (CRS). Third, both parties eliminate trade promotions, as the customer does not want to forgo potential forward-buying profits. To compensate, the supplier will maintain a constant price for the VMI good or service, lower than the regular price (Cachon & Terwiesch, 2013, p. 386 f.)

In contrast to a classic pull-principle, the inventory responsibility, using VMI concept, is shifted from the customer to the supplier. The supplier is responsible to meet the mutual predefined minimum and maximum quantities in stock at the customer's warehouse. Depending on the different material, the minimum and maximum quantity stock can vary widely. Relevant for determining these boundaries are the dimensions, the value and the demand situation (constant, sporadic) of the material. To realize an efficient demand control, replenishment is based on a demand-driven supply instead of an on-time delivery. As already mentioned, the required data about inventory at the customer's warehouse are exchanged via 'Electronic Data Interchange' (EDI), 'Extensible-Mark-Up-Languages' (XML) communicating with the 'Enterprise-Resource-Planning-System' (ERP-System) of the customer, or a web based platform (Hirzel, Geiser, & Gaida, 2013, p. 300). These systems provide additional information about consumption data, possible shortages, and forecasts, whereby the supplier can control and optimize the production planning and adjust actual demand (Hirzel, Geiser, & Gaida, 2013, p. 134). A compatible information system to coordinate the procurement process between both parties and daily data about the customer's inventory are required. The former must provide a secure data exchange between supplier and customer (Placzek, 2007, p. 142). The VMI concepts also requires a basis of trust between both parties, as internal data is transmitted.

Although transfer of ownership is a marginal aspect within the VMI concept, both parties should be aware of the determined modalities. On the one hand, transfer of ownership can take place at the point of delivery at the customer. On the other hand, transfer of ownership can also switch when the customer withdraws the material from the warehouse to provide it for manufacturing. In the latter case, before withdrawing, the ownership is attributed to the supplier, even though the material is already in the warehouse of the customer (Hausladen, 2016, p. 158). This approach is described as 'Consignation Concept' (see 2.3 Consignment Warehouse Concept). A conventional implementation of VMI describes an entirely management-function of the supplier, to control and maintain inventory at the customer's warehouse downstream in the supply chain (Klaus, Krieger, & Krupp, 2012, p. 609). Invoicing and payment are not specified and can vary between an invoicing process by the supplier or credit note procedure by the customer.

Time and quantity of the delivered material are within the supplier's responsibility and therefore the VMI concept pertain to the so-called 'push-principles'. The key figure of this system is that material replenishment occurs in anticipation of demand. Pull systems prevent the excessive buildup of inventory and are most effective when average demand remains steady (Cachon & Terwiesch, 2013, p. 294). Figure 3 shows a detailed procurement process with VMI between supplier and customers via a VMI-portal.

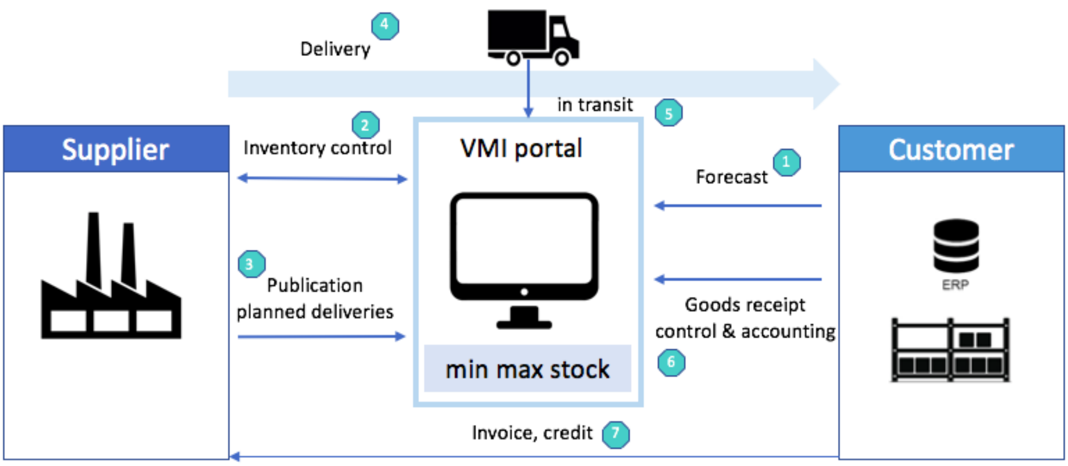

Figure 3: Process of VMI based procurement. Source: Own figure based on (Rüger, 2004).

The transaction of the whole procurement process based on VMI requires a minimum and maximum stock and the customer's warehouse that us predefined between both parties. This stock is recorded within the VMI portal and can be adjusted cooperatively. The optimal minimum and maximum stock for Plant Vienna is research base for the underlying master thesis and will be described in chapter 5. The ERP-system transmits the present inventory in the customer's warehouse and customer's future demand automatic and periodic (1). It is the supplier's obligation to control the inventory and to plan production based on received data (2). When the supplier prepares a delivery to the customer, the supplier must provide delivery and transport data in the VMI portal (3) (Appelfeller & Buchholz, 2011, p. 249 f.). Depending on the operational capability of the VMI portal, a dispatch notification can be made out, which automatically transfers to the ERP-system of the customer. The physical transport (4) can be displayed in the VMI portal with the collection time at the supplier and approximately delivery time at the customer as well as the delivered quantity (5). As soon as the delivered material was checked at the goods receipt and posted in the ERP system, the inventory stock gets updated (6). To finalize the process, either the supplier invoices the delivery or the customer issues a credit (7).

There is no explicit or universal definition as to which material is best suited to be processed via VMI. It depends on several aspects, like market (short or long cycle times), manufacturing schedule at the customer's side or properties of the material (dimensions, value, turnover rate). Additionally, the company's strategic orientation towards the supplier are an important part in the implementation of VMI. The supplier must guarantee a high performance and reliability, as the customer's dependence on the supplier increases with VMI. In general, suitable goods are of big volume, continuous demand and simultaneously of high turnover rate. Further, a setting of series production at the customers manufacturing qualifies for VMI. In this case, several similar products are produced, which cause a high demand of constant demand of raw materials and materials (Stollenwerk, 2016, p. 300). This assumes a VMI procurement process of material with high value and constant demand (AX material). Here, 'just-in-time' (JIT) or 'just-in-sequence' (JIS) are also possible. However, material with high value and unsteady demand (AY material) can also be suitable for a VMI procurement process, as responsibility for the inventory stock at the customer's warehouse switches to the supplier. Depending on the external and internal factors influencing the procurement process, production and manufacturing, both parties need to analyze and decide whether the VMI concept is suitable or not. High value material as well as C material can be disposed via VMI (Vahrenkamp & Kotzab, 2012, p. 220).

Tables 1 and 2 show the advantages and disadvantages of the VMI concept for the customer and the supplier, table 3 shows advantages and disadvantages of both parties working together.

Customer	
Advantages	**Disadvantages**
○ Transfer inventory responsibility to supplier ○ Demand driven delivery ○ Inventory reduction ○ Decrease of material, process, inventory and capital commitment costs ○ Drop of material rage and simultaneously improve of material availability	○ Disclose information about inventory, demand and forecast to supplier ○ Confidence in supplier ○ Hand disposition core competency over to supplier

Table 1: VMI Advantages and Disadvantages for the Customer. Source: Own table based on (Hirzel, Geiser, & Gaida, 2013) and (Melzer-Ridiner, 2004)

Supplier	
Advantages	**Disadvantages**
○ Supplier driven inventory management ○ Direct access to inventory data, demand data and forecast data ○ Independent delivery ○ Production optimization due to adjusted production ○ Increase of service level ○ Guaranteed revenue and impact on procurement process of customer	○ Permanent online access to VMI portal ○ Monitoring and control of minimum and maximum stock in VMI portal ○ Mandatory adherence of minimum and maximum stock in warehouse ○ Increase in control effort

Table 2: Advantages and Disadvantages for the Supplier. Source: Own table based on (Hirzel, Geiser, & Gaida, 2013) and (Melzer-Ridiner, 2004).

Customer and Supplier	
Advantages	**Disadvantages**
- Collaborative partnership - All-automatic ordering process - Electronic managed business relation - Previous testing of Co-Managed-Inventory before implementing VMI	- Data security must be guaranteed - High costs in the event of non-compliance with minimum and maximum stock

Table 3: Advantages and Disadvantages for both parties. Source: Own table based on (Hirzel, Geiser, & Gaida, 2013) and (Melzer-Ridiner, 2004).

Co-managed Inventory can be used when lack of trust between supplier and customer exists. In this case, inventory responsibility is not well developed compared to a complete VMI implementation. The supplier transmits delivery and inventory proposals and the supplier checks those proposals whether they are acceptable or not. In the trial phase, co-managed inventory can be implemented, where the suitability of the supplier can be verified. (Placzek, 2007, p. 143).

3.1.2 Contract Warehouse Concept

The concept of a contract warehouse includes the idea, that a contractual agreed quantity of material is stored at the suppliers' warehouse. Via a short-term call, material is delivered to the customer. Only with the delivery, the invoicing of the ordered material is completed (Stollenwerk, 2016, p. 301). The main idea behind this concept is to move all physical inventory and handling processes from the customer's warehouse to the suppliers. Depending on the warehouse and production situation at the customer's plant, zero inventory or a minimum stock of inventory can be planned.

It is possible to transfer the warehousing responsibility to a third-party logistics service provider (Koch, 2012, p. 171). Depending on the geographical proximity of multiple suppliers for one customer, there is potential for an inventory combination of the materials that can be overseen by the logistics service provider. Moreover, delivery combination of the different materials from the multiple suppliers and therefore costs saving through optimized deliveries; this would be an additional effect of combined warehousing via a logistics service provider. Another possibility is to implement JIT-deliveries from the contract warehouse, independent as to whether the contract warehouse is at the supplier or service provider.

In general, contract warehouses should be located in a certain distance to the customer's plant. Due to demand and requirement fluctuations and the zero or minimal stock at the customer's warehouse, the contract warehouse location must enable a short-term delivery of the needed

material. The so-called "certain distance" depends on the sourcing strategy of the producing company, whether it is local sourcing, domestic sourcing or global sourcing.
The whole process of contract warehousing can also be transacted via VMI. It allows more inventory, production and delivery control. The predefined minimum and maximum stock levels are transferred to the contract warehouse at the supplier's side. Using the VMI tool, both the supplier and customer, can provide either demand forecast or delivery forecasts. It supports responsiveness and communication, and therefore boosts trust between both parties.

Figure 4 shows that the transfer of ownership takes place after the material is called and delivered from the contract warehouse to the customer. As soon as the material is delivered, it is provided for manufacturing without additional storage at the customers warehouse. Control of quality of the material can either be done at contract warehouse goods issue before shipment or at the incoming goods inspection at the customer's plant. This aspect needs to be determined and agreed on by contract beforehand.

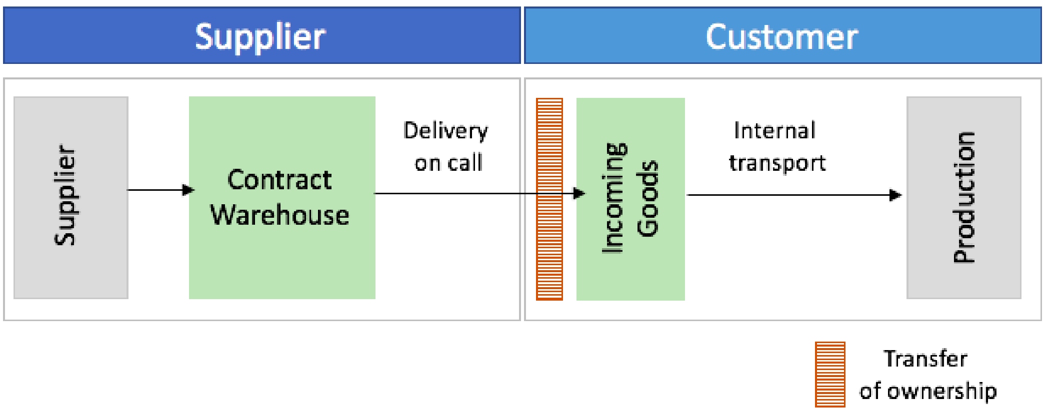

Figure 4: Contract Warehouse without logistics service provider. Source: Own table based on (Koch, 2012).

Tables 4, 5, and 6 show that there are advantages and disadvantages on both sides when implementing a contract warehousing model.

Customer	
Advantages	**Disadvantages**
o Low capital commitment costs and simultaneously high security of supply o Reduction in processing expenditure o Decreased storage risk	o Risk of short-term low material availability o Limited access to material o Slow material flow o Increases dependency of supplier o Additional costs for storage outsourcing

Table 4: Advantages and Disadvantages of Contract Warehouse for the customer. Source: Own table based on (Stollenwerk, 2016) and (Koch, 2012)

Supplier	
Advantages	**Disadvantages**
o Cost saving to optimized production o Close customer relationship o Constant transportation volume o Stable prices for material	o Additional costs for third party logistics service provider o Cost coverage for warehousing and insurance o Increased total risk

Table 5: Advantages and Disadvantages of Contract Warehouse for the supplier. Source: Own table based on (Stollenwerk, 2016) and (Koch, 2012).

Customer and Supplier	
Advantages	**Disadvantages**
o Intensification of cooperation o Long-term partnership o Possibility of VMI combination	o Mandatory guarantee of both-way benefit

Table 6:Advantages and Disadvantages of Contract Warehouse for Customer and Supplier. Source: Own table based on (Stollenwerk, 2016) and (Koch, 2012).

Supply and demand of material processed between a supplier and customer processed via a contract warehouse should be of constant requirement. Nonetheless, material with inconsistent demand can be stored, ordered, and delivered with the contract warehouse concept. Each partnership between a supplier and the customer needs to be explicitly analyzed before implementing a contract warehouse; in addition, every single material should be considered in detail.

3.1.3 Consignment Warehouse Concept

Based on Vendor Managed Inventory, the idea behind the consignment warehouse concept is the transfer of ownership. As the word origin indicates, *consigno* comes from the Latin word for certificate and document (Stowasser, 1971, p. 131). The customer provides a specified area in its own warehouse, specifically for the material of the supplier. After delivery and storage at the customer's warehouse, the material is property of the supplier until a contractual agreed point of time, usually the withdrawal of the material from the warehouse for manufacturing. Therefore, the Consignment Warehouse Concept includes a specialized form of transfer of ownership.

The supplier is still responsible for material availability and disposes independently (Melzer-Ridiner, 2004, p. 173). The inventory of the material included in the contract warehouse is in the property of the supplier, although it is already located in the warehouse of the supplier. This material must not be calculated into the inventory level of the customer and accounts to the supplier until the material is withdrawn for manufacturing (Gudehus, 2010, p. 983).

The concept of consignment warehouse is often implemented in combination with VMI, but it is not mandatory.

For Plant Vienna, consignment warehouse is no alternative procurement model due to the limited inventory capacity. Therefore, this concept will not be elaborated in detail. Siemens AG in Krefeld uses this concept with several suppliers and its logistics service provider.

3.1.4 Realistic implementation at Plant Vienna

The concepts of VMI and CW are already implemented between several suppliers and Siemens AG Austria Plant Vienna. Geographical proximity to Plant Vienna and material of big dimensions, with constant demand, are some similarities between the suppliers. Vendor Managed Inventory and Contract Warehouse generate positive effects to the current situation at Vienna plant and shall therefore be put into practice with more suppliers.

Another concept that supports the implementation of VMI and CW is the returnable rack circulation system. Instead of one-way packaging, which produces additional costs for unpacking, handling and disposal, Plant Vienna operates a system of returnable racks. These racks replace one-way packaging and are designed in particular for specific material, e.g. doors, windows or bellows. Goods receiving and material provision are improved as well as unpacking and disposal do not occur. As purchasing of returnable racks can be relatively costly in comparison to one-way packaging, the quantity of returnable racks in circulation with a supplier is limited. The quantity of racks should enable a smooth circulation of deliveries and return deliveries. Within the VMI and CW context, the idea behind returnable racks is that the supplier should only be allowed to deliver only when there are sufficient racks available for a suitable delivery batch.

Even though VMI and CW promise a lot of benefits, they also come with many disadvantages, some of which Plant Vienna already struggles with as it lacks a high implementation rate of VMI and CW. Low material availability, limited access to material, non-conformity costs, and a slow flow of material are the main issues and result not only from static order processes. Reasons for this might be the general project-based environment, in which time, quality and costs determine between success or failure. Communication between supplier and Siemens AG Austria as well as long and inconsistent communication channels within Siemens AG Austria complicate an efficient inventory and transportation management. There is no universal tool for the whole processing of VMI and CW between supplier and Siemens. Now, several tools are in use as well as parallel E-Mail communication. Even though Siemens applies different tools for the VMI realization, both lack of essential functions and instead of simplifying communication and order processes, additional expenses are performed and charged. Unclear definition of responsibility and lack of coordination in a supplier and customer relationship hurts the overall performance. From Siemens' side, more than two departments are involved in the VMI implementation, theoretically and practically. Another main problem is the self-serving behavior of both parties, wherefore necessary information does not get shared adequately. In some cases, information overload impedes a lean and constructive communication. Different departments within Siemens AG Austria strive for conflicting objectives. Siemens employees have different attitudes towards VMI and generally the implementation of new concepts and ideas. Too many interfaces with the supplier results in contradictory information, which leads to confusion and loss of trust.

To overcome internal conflicts, Siemens AG Austria needs clearer communication channels next to uniform objectives with defined appropriate prioritization, distinct responsibility, employee commitment, and one efficient tool. Not before internal structures are optimized by a competent and strong management and further adapted by the employees, Siemens AG Austria needs to implement nearly the same to strengthen and improve the relationships with its suppliers.

3.2 Collaborative procurement conversion effects

Changing procurement processes within a supply chain affects both, the supplier and the customer. Conversion effects include physical and dispositive adjustments and lead to redefined information and decision-making processes. Operative and strategic management tasks are required when shifting responsibility from conservative to new processes.

Figure 5 shows the affected divisions, when changing the procurement processes to a collaborative system.

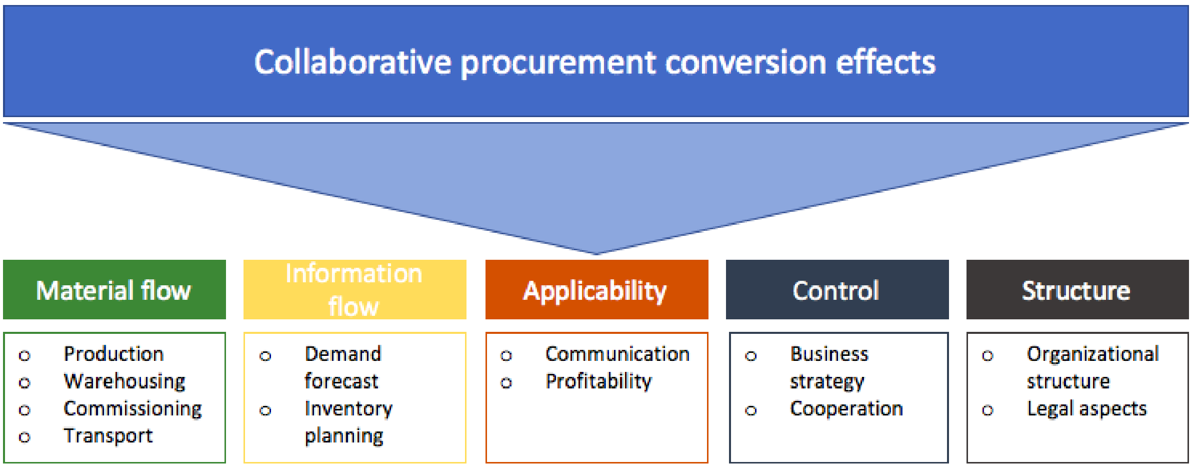

Figure 5: Conversion changes of collaborative procurement. Source: Own figure based on (Witthaut, 2015).

Within the material flow, changes in the production planning of the supplier might occur. There is potential to reduce setup costs, optimize production lot sizes and reduce administrative work. Another aspect is changes in warehousing. Depending on the chosen procurement model, inventory levels of both parties are influenced. Commissioning and goods provision might change, and the organization of transport needs to be adjusted.

With the presented collaborative procurement models, the supplier is responsible for the inventory level, which requires a constant and transparent information flow between both parties. Essential for this is the forecast demand provided by the customer. Both parties need to work together to profit from this conversion; a fundamental basis of this model is a reliable and cooperative communication between supplier and customer. Both parties should strive for a long-term business strategy to coordinate cooperation for a mid- to long-term business partnership. The organizational structure needs to be adjusted as well. Aim is to reduce processing times on both sides, to increase process quality and simultaneously reduce costs. Legal aspects also need to be considered, due to the special feature of transfer of ownership and risk.

The restructuring process for Siemens AG Austria plant Vienna requires all of the mentioned conversion effects. Focus will be placed on warehousing and transport aspects. Inventory at Plant Vienna will be planned based on VMI as well as transportation combination from a single or several suppliers to Plant Vienna. The following chapters will guide through the calculation of the optimal minimum and maximum inventory stocks for current projects based on potential VMI suppliers.

4 Determination of potential suppliers

The basis for a conversion of the procurement process are mutual interests in a long-term business partnership and ongoing cooperation. Both parties, supplier and customer, need to establish a high level of trust, constant and transparent information flow and the same aim of optimizing supply chain coordination.

Plant Vienna has more than 500 different suppliers, and not all of them are suitable for a continuous relationship with Siemens AG Austria. Therefore, a key valuation indicator was developed in cooperation with Plant Krefeld, which evaluates the potential of one supplier for an innovative procurement model.

In combination with the key valuation indicator, a criterion catalog will be developed, to combine qualitative and quantitative measures.

The key valuation indicator consists of three different ordinal measurable parameters, calculated for each single supplier. Quantitative measures are purchasing volume, quantity of delivery schedules and delivery reliability of the preceding fiscal year. Purchasing volume (PVO) indicates the revenue of one supplier generated with Siemens AG Austria within one fiscal year. PVO is measured in monetary units. Delivery frequencies of one supplier are also considered. Here the actual deliveries of one supplier to Plant Vienna are considered. One order can consist of multiple deliveries, as the total order quantity is not meant to be delivered all at once. Delivery intervals and internal production adjustment at the suppliers' side can be scheduled bilaterally. Announced delivery dates of single delivery schedules are exactly planned and Plant Vienna is expecting an incoming goods receipt. The last element of the key valuation indicator is each individual delivery reliability of the suppliers. This parameter provides information about the availability of delivered material, delivery quantity and product quality. All required information is provided by the company-wide used ERP-system.

To calculate the key valuation indicator for each supplier, the strategic logistics team at Plant Krefeld weighted each of the parameters differently. PVO is calculated with a weight of 70%, where quantity of delivery schedules is weighted with 20% and delivery reliability with 10%. The resulting key valuation indicator recommends, based on quantitative data, the most suitable suppliers for an innovative procurement model. Besides the key valuation indicator, the potential suppliers need to meet minimum requirements. To be nominated the minimum PVO is set at € 5,000000.00, the minimum quantity of delivery schedules shall not be less than 500 and the supplier's delivery performance should have at least a delivery reliability of

75%. In addition to the quantitative analysis, Plant Krefeld plans to develop a criteria catalog based on qualitative measures.

Based on the quantitative data analysis for Plant Vienna provided by Plant Krefeld, the strategic logistics department at Plant Vienna edited the list of potential suppliers. Reason for this is the limited storage capacity. Within this framework, we added some more suppliers to the potential VMI candidates, which do not fulfill the minimum requirements exactly, but due to their material dimensions and proximate location to Plant Vienna, they were still nominated.

5 Optimal minimum and maximum stock

Starting from the analysis of potential suppliers for Plant Vienna, optimal minimum and maximum stock was calculated. Before calculating, data about every supplier, the delivered material, dimensions of the packaging, delivered batch size and storage conditions of the material were collected.
The latter required a detailed registering of the different storage area types at Plant Vienna. Material like windows or doors need to be stored in a temperate warehouse and cannot be stored in an outdoor warehouse. Air conditioners and seats can be stored in a cold internal warehouse and bellows can be stored outside on a short-term basis.

5.1 Warehouse types and storage area at Plant Vienna

Due to cost saving reasons, management of Siemens AG Austria decided to close its external warehouse at the headquarter of Siemens AG Austria in 1210 Floridsdorf, Vienna. Overall storage area at Plant Vienna are 16,514 square meters, which are divided into areas especially for shell construction, C-parts, or chemical goods. Subtracting these non-relevant storage areas, the remaining space is only about 8,869 square meters (3,517 pallets and 5,253m²). Before closing the external warehouse, there were about 6,379 additional square meters available for A and B material. The reduced storage area can be further divided into internal temperate warehouses, internal cold warehouses, outdoor storage roofed, and outdoor storage not roofed. Table 7 shows an overview of the different types of storage areas at Plant Vienna. Due to this division, the calculation of the optimal minimum and maximum stock for each material had to consider the individual storage conditions of each material.

Storage Areas (plant Vienna)	Pallets (1,2m x 0,8m) (1)	Block m² (2)
Temperate internal **A**	2,451	1,425
Cold internal **B**	1,066	562
Outdoor storage roofed **C**	---	3,065
Outdoor storage. **D**	---	300
TOTAL	3,517	5,352

Table 7: Storage Areas at Plant Vienna.

Based on the available storage areas and warehouse types, material for the minimum and maximum inventory calculation was assigned to one of the four storage areas, depending whether it can be stored on a pallet or block. For the data collection, the storage areas and inventory types were combined. Windows, for example, were assigned to A2, which means that they should be stored at a temperate internal warehouse of type block, as glass is one of the most sensitive materials concerning storage conditions at Plant Vienna, and windscreens can be of high dimensions and are therefore not suitable for pallet storage.

5.2 Data collection

Starting with a list of 28 potential VMI suppliers for Plant Vienna, each supplier was analyzed based on its material scope for each current project. In May 2017, there are eight projects simultaneously manufactured or soon starting to be manufactured at Plant Vienna. Three of the eight projects are tram projects, another three are metro projects, one passenger coach project and one tired light rail project. These four types of projects differ in their complexity, comparing a tram with a passenger coach, and they also differ in their scope of ordered trains. Therefore, the quantity of the main components of a train, like seats, doors, air conditioners, vary between these projects.

The data collection started with general information about the supplier, vendor number and address. For each project, the supplier delivers material, the specific quantity contract and material numbers were extracted from the ERP-system. Not every supplier delivers for each project. Although couplings for each project are delivered from one single supplier, components like seats, doors and windows have different suppliers.

To calculate the optimal minimum and maximum stock level, the packaging unit of each delivery of each material, based on the quantity contract of each supplier for each project, needed to be measured. Staying with the coupling example, there is not only one coupling per train, but there can be up to four different types of couplings for one project with different quantities. Nevertheless, the packaging unit dimensions for couplings are always the same. One delivery of couplings from supplier A can consist of up to four different types of couplings, with different material numbers but the same packaging unit dimensions. Depending on their stackability possibilities, the floor area of each packaging unit was calculated and added together manually. As couplings are a simple example, components like seats are more complicated. One quantity contract of one supplier for one projects consists of 27 different material numbers, which means that there are 27 different types of seats, each of them with a different quantity. One delivery of these seats includes 127 seats in total, which are shipped in 14 packaging units with three different dimensions. Altogether, one delivery needs up to 20m² storage area.

Table 8 shows a simplified data collection, where the dimensions of each packaging unit are calculated and added together to display the needed floor space for one car and, depending on the delivered lot size and stackability, of each delivery. The suitable warehouse is also determined in this table. Even though this way of data collection is quite complex, it allows the user to trace back each material to each project, supplier, quantity contract and warehouse type.

Project	Supplier	Quantity Contract	Material	Quantity (project)	Packaging Units	Qt. per packaging unit	Length (mm)	Width (mm)	Height (mm)	Floor space/car (m²)	Floor space delivery (m²)	Warehouse
1	A	123	Coupling 1	21	1	1	1200	800	600	0.96	1,92	B1
1	A	123	Coupling 2	42	2	1	1200	800	600	0.96		B1
1	A	123	Coupling 3	42	3	1	1200	800	600	0.96		B1
2	B	456	Seat 1	166	4	1	2400	1700	1500	4.08	19.0016	B2
2	B	456	Seat 2	996	4	6	2400	1700	1500			B2
2	B	456	Seat 3	166	4	1	2400	1700	1500			B2
2	B	456	Seat 4	332	4	2	2400	1700	1500			B2
2	B	456	Seat 5	498	5	3	2400	1700	800	4.08		B2
2	B	456	Seat 6	166	5	1	2400	1700	800			B2
2	B	456	Seat 7	166	5	1	2400	1700	800			B2
2	B	456	Seat 8	332	5	2	2400	1700	800			B2
2	B	456	Seat 9	664	6	4	1600	1676	1025	2.68		B2
2	B	456	Seat 10	996	6	6	1600	1676	1025			B2

Table 8: Data Collection.

For this thesis, information of about 500 material was collected, analyzed and calculated.

The next step includes the mathematic basis for the optimal minimum and maximum inventory levels for each project. Within this framework, the Newsvendor model is used as a basis for a periodic inventory management.

5.3 The Newsvendor Model

Theoretical basis for the calculation of optimal minimum and maximum stock for each project at Plant Vienna is the Newsvendor model. This model is drawn upon the situation of uncertain demand and a single order opportunity. Costs occur when the order quantity is too high, which is the leftover inventory, or when the order quantity is too low, which is the opportunity cost of lost sales. The Newsvendor model balances these two costs and aims for the optimal amount to order (Cachon & Terwiesch, 2013, p. 240 ff.).

In general, the Newsvendor Model describes a situation in which one single product is ordered once at the beginning of a period and which can only satisfy demand occuring in this period. Demand D is given as a continuous nonnegative random variable with a density function *f(x)* and a cumulative function *F(x)*. The optimal order quantity Q^* is objective to this model, which should be determined to minimize the expected costs of overage costs C_o, leftover inventory, and underage costs C_u, lost sales, which might incurr at the end of the period.

As demand is uncertain in the Newsvendor Model, the probability of demand needs to be chosen. Therefore a distribution function is used, as a random variable is specified by its distribution function. For the Newsvendor model two forms of distribution functions can be used, the 'Discrete Distribution Function' and the 'Continuous Distribution Function'. The former has exactly one possible outcome for one probability, whereas the latter provides an unlimited number of possible outcomes (Cachon & Terwiesch, 2013, p. 244).

Using the 'Standard Normal Distribution Function', which is a continuous distribution but can also be considered in pieces which would make it a discrete distribution, *mean* = μ and *standard deviation* = σ are needed. To use the normal distribution, the *z-statistic* is used. To find out the probability whether demand is either less than or equal to Q, we need to evaluate the *z-statistc.* This formula is also known as the critical ratio (CR):

$$z = \frac{C_u}{C_o + C_u}$$

Formula 1: Calculation of the z – statistic

According to the 'Standard Normal Distribution Function', the z-value belongs to the probability of demand Φ (z-value) (Cachon & Terwiesch, 2013, p. 250).

Continuing with the Newsvendor Model, inputs for calculating the profit-maximizing order quantity and further performance measures, like expected lost sales or expected profit, must be assembled. Selling price, cost, salvage value and demand forecast are required. The formula to find the optimal order quantity which maximizes the expected profit is:

$$Q = \mu + z \times \sigma$$

Formula 2: Optimal Order Quantity

In our case, total demand is certain. The overall scope of each project is determined in advance, but due to internal and external risks exact demand per month can vary. Internal risks can occur because of postponements in manufacturing or material damages during storage or manufacturing. External risks might happen during transport, which can be delayed or quality of the delivered material is insufficient. These variations and risks occur irregular and complicate an exact estimation of the forecast and forecast error.

Similar to the Newsvendor Model, Siemens AG Austria tries to order the optimal quantity of material to have in stock, to satisfy demand while coping with limited storage area. In context of the VMI approach, the optimal order quantity corresponds to the maximum inventory level. In addition, the safety stock will be determined with the same model.

5.4 Average demand and deviation for each project

The first step to find the optimal order quantity and safety stock for Plant Vienna, average demand and deviation must be determined.

Framework conditions of projects at Plant Vienna are duration and cars built per month for each project. Both conditions vary between the current projects and within each project. Smaller projects have a duration of only a few months, but bigger projects will be built for up to three years. Starting with just a few cars per month, manufacturing can be increased due to capacity reasons, to prevent idle times at the plant.

Before evaluating μ and σ, the use of the 'Standard Normal Distribution Function' needs to be checked. Therefore, the distribution for each project over the total project duration was considered. With the use of each projects production plan, the monthly output of cars was visualized as a histogram. Figure 6 is shows the output of the production plan for project 4 as a histogram. Here, the bell-shaped-curve is visible to some extent. On the x-axis, the monthly output of cars is presented, whereas on the y-axis the frequency of two, four, six or eight cars during the whole project duration are indicated.

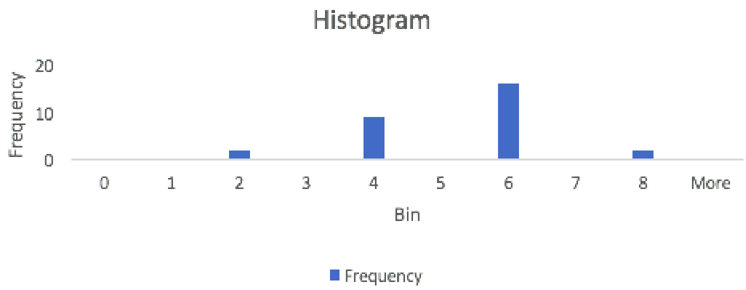

Figure 6: Production Plan Histogram. Source: Own figure based on production plan of project 4

Assuming that the use of the 'Standard Normal Distribution Function' is appropriate for the evaluation of the optimal order quantity (maximum inventory level) and the safety stock (minimum inventory level), the next steps include the calculation of the mean average and deviation for the current projects.

For each of the eight projects, the average quantity of car sets manufactured per month was calculated as well as the standard deviation. The former equals to the average monthly demand in car units. Given the project base plan, were the monthly output of car sets are forecasted, the following table works as a project overview.

Project	Average amount of cars build per month μ	Standard deviation σ
1a	8	5.7
1b	4.5	1.6
1c	3	1.1
2	8.6	3.8
3	2.3	0.8
4	5.2	1.5
5	12	5.2
6	3.2	2
7	4.3	2.8
8	3.3	1.8

Table 9: Project Overview.

Two things are noticeable about this table. The first is project one, which is divided into three sub-projects. Reason for this are the varying number of cars per train. Project one consists of trains with two, three or four cars per train. Therefore, we had to divide this project into three sub-projects. The second unusual remark is the standard deviation. Project 1a and 5 show a particularly high standard deviation. There are two reasons for this. Firstly, as already mentioned some projects have a duration of only a few months and imagine in the first month there will be 3 cars manufactured, in the second 10 cars and in the last month also 10 cars. Secondly, we observed the whole duration of a project. Over the time frame of about three years and due to financial or capacity reasons at Plant Vienna, in some months there will be more cars manufactured than in the other months. Both reasons lead to unusually high standard deviations. One countermeasure could be to calculate the average number of cars built per month along with the standard deviation not for the whole duration, but for a determined period. Considered the project situation and internal processes at Plant Vienna, one recommendation would be to take into account only the next 4 months. This would lead to a more precise calculation, but at the same time greater effort. For this master thesis, we considered the whole duration of the projects and calculated the next steps with the numbers above.

In contrast to the Newsvendor Model, processes at Plant Vienna allow numerous replenishments originating from one total quantity order. During running projects, inventory gets refilled when demand occurs. Materials considered in this thesis are delivered in bilateral agreed lot sizes between the supplier and Siemens AG Austria. For example, a lot size called and delivered per month might consist of the quantity of doors for one train (this might be 8 doors), although the total order quantity is the amount for a multiple number of trains. As obsolescence is not a major concern during running projects (this statement is not valid when projects are finished, but the quantity ordered exceeds the actual quantity manufactured), material ordered but not used in the same month can be manufactured at a later stage.
For the further calculation of the optimal minimum and maximum inventory level at Plant Vienna, the ‘Order-Up-To Inventory Model’ is used.

5.5 Order-Up-To Inventory Model

As many products are sold over a long-time period with numerous opportunities to replenish, the ‘Order-up-To Inventory Model’ also faces the challenge of matching supply with demand. Ordering too little leads to undesirable stock outs, ordering too much results additional inventory holding costs. The objective of the ‘Order-Up-To Inventory Model’ is to balance of running too lean and running too fat (Cachon & Terwiesch, 2013, p. 287).

In contrast to the *Newsvendor Model*, the 'Order-Up-To Inventory Model' and the VMI approach are both classified to periodic inventory management. Leftover inventory at the end of a period can be used in the following period and therefore does not generate salvage value. Instead inventory holding costs might occur. The order process in the actual period influences not only the inventory level in this period, but also in the following periods (Thonemann, 2010, p. 222).

In the basis model, the delivery lead time equals zero and the desired inventory level is determined at the beginning of each period. This does not hold when delivery lead time is bigger than zero, but a situation with delivery lead time > 0 is not relevant in this case. Order quantity X_t in the basis model is evaluated by determining the target stock $S*$ in period t. To calculate the order quantity, one has to substract inventory stock at the beginning of this period I_t from the target stock $S*$:

$$X_t = S^* - I_t$$

Formula 3: Order Quantity

An example of a periodical process of inventory level can be seen in figure 7.

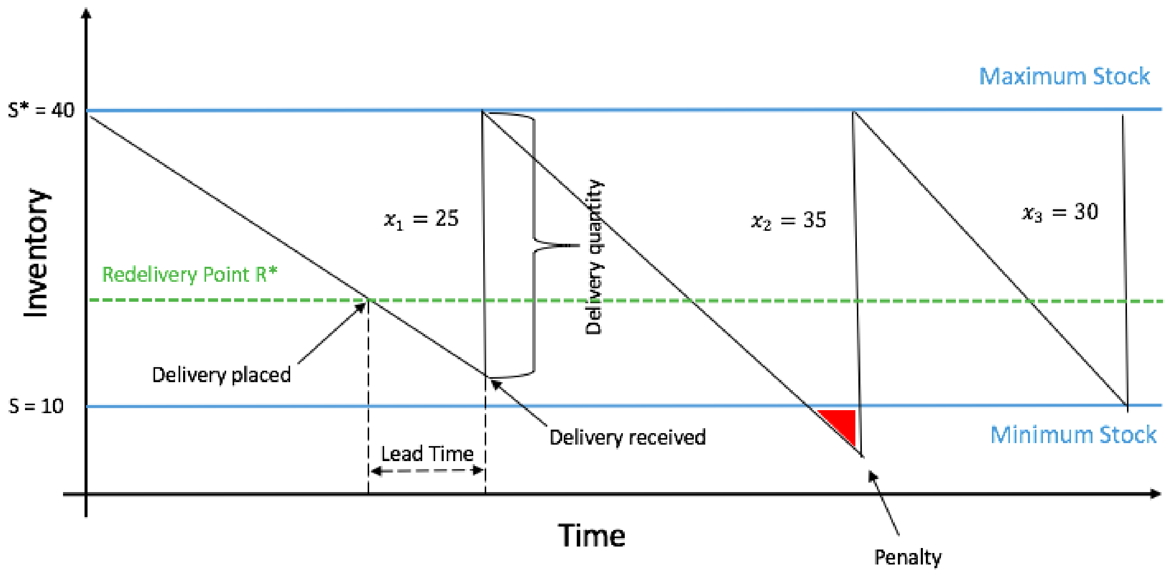

Figure 7: Order Cycle. Source: Own figure based on (Thonemann, 2010).

The diagram shows the time periods on the x-axis and the inventory level on the y-axis. The blue lines present the safety stock S and the target stock S^*. The actual inventory level is described with the black line. The redelivery point R^* can vary, depending on the delivery schedule of the supplier and demand. Between the point where a delivery is placed and a delivery is received, is the lead time, which needs to be considered in production and delivery planning of the supplier. The red area illustrated a shortfall of the minimum stock where penalty costs occur.

In this example safety stock, target stock, and order quantity are given. For our case, we want to determine the optimal minimum and maximum inventory levels with the constraints of limited storage capacity, parallel projects, several suppliers, multiple components, and uncertain monthly demand. To find the optimal solution, we use the Standard Normal Distribution Function from part 5.3 and use the formulas for optimal target stock S^*:

$$S^* = \mu + z \times \sigma$$

Formula 4: Optimal Target Stock

and safety stock *ss:*

$$ss = z \times \sigma$$

Formula 5: Safety Stock

Safety stock is needed, as we must deal with uncertain demand. If demand would be certain, deviation would equal zero and we would not need any safety stock (Thonemann, 2010, p. 232).

From part 5.3.1 we already know each projects' mean average demand per month and deviation. The last missing part to finally calculate our optimal minimum and maximum inventory level we need to determine the z-value. Getting back to the Newsvendor Model, we would need some underage and overage costs to determine the z-value. Given the complexity of Plant Vienna, one simple value for a generally valid C_u and $C_o$is not possible. Lost sales would comprise not only the material value of the missing component, but also resulting idle times of workers and machine, project delay, overtime hours to catch up and in the worst-case delay charges of the end customer, because the end product is not delivered in time. Leftover inventory could be estimated simpler, because redundant material just needs to be disposed. In general, A and B material cannot be used in other projects, as they are especially designed and produced for one specific project. In contrast, C material is used over all projects and therefore no overage costs would occur.

Another approach to determine the z-value would require holding costs and penalty costs. In this case, the critical ratio is calculated the same, as penalty costs p replace the underage costs C_u and overage costs C_o are replaced by holding costs h:

$$CR = \frac{p}{(h + p)}$$

Formula 6: Critical Ratio

Holding costs are estimated at €10.00 per square meter at Plant Vienna and therefore easy to implement. On the contrary, penalty costs are similar to the underage costs. There are multiple factors influencing penalty costs, which do not exist in this form. Additionally, penalty costs may need to be calculated for each material, which is not delivered in time or does not correspond to the conditions for manufacturing. Nevertheless, delay can also occur due to technical or manufacturing problems, independent of optimal material conditions. Non-conformance costs (NCC) might be the closest equivalent value for penalty costs, but there is no general valid value, which could be used. Instead, non-conformance costs are estimated and discussed within a project, because all occurring costs which differ from the planned budget merge in the NCC.

Both approaches do not work with our situation. Since we cannot find a way to calculate a suitable way to determine our critical ratio, we need to reconsider our objective.

5.5.1 Service Level Alpha

With the given situation of extreme complexity and complicated cost structures, we need to know, what we are aiming for. The α - service level is one approach to use the Newsvendor Model in combination with the Order-Up-To Inventory Model to finally find the optimal minimum and maximum inventory levels.

In the environment of a periodic inventory management, the α - service level indicates the probability that all customer orders will be met from stock, or the probability that inventory at the end of the period does not get negative (Tempelmeier, 2006, p. 184). Logically, this probability should be as high as possible considering the resulting high results for minimum and maximum stock and the related needed space and holding costs.

Not knowing which α - service level might be appropriate and under the condition that we can not prefer a project to the remaining projects, we calculated the optimal minimum and maximum inventory level with 32 different α - service levels starting with 85% and ending with 99.9%. The corresponding z – values and results can be seen in the attached storage medium.

The calculation of the optimal minimum and maximum stock was made for each of the eight projects presented in cars produced per month, as well as the corresponding necessary square meters for all warehouse types and for each single warehouse type and the resulting holding costs.
The overall generated data volume exceeds readable representation possibilities, therefore we will pick out two α - service levels and continue with the calculation.

To show the extreme sensitivity of the α - service level, we chose 85% as α_1 and 99.9% as α_2, with the corresponding z-value of 1.04. For demonstration reasons, we will stick with project 4 and its mean μ = 5.2 and deviation σ = 1.5. The result for safety stock is:

$$1.04 \times 1.5 = 1.56$$

and target stock is:

$$5.2 + 1.04 \times 1.5 = 6.76$$

The results must be seen as cars per month. The quantity of material of project four for safety stock must equal the required quantity of 1.56 cars vice versa for target stock of 6.76 cars. Thus, the optimal minimum inventory level and maximum inventory level with a probability of 85% that all production requests can be fulfilled from stock are 1.56 cars and 6.76 cars.
We will calculate the same for a α_2. Here, the corresponding z-value is 2.99 and leads to the assumption that safety and target stock will be significant higher than for α_1.
Safety stock:

$$2.99 \times 1.5 = 4.49$$

Target stock:

$$5.2 + 2.99 \times 1.5 = 9.69$$

The recognition from this comparison is that the higher one pursuits a α-service level, the more material needs to be in stock. Table 10 shows the results expressed in overall required square meters and holding costs per month at Plant Vienna of project 4.

Service-level α	Min cars	Max cars	Min m²	Max m²	Min Holding costs	Max Holding costs
85 %	1.51	6.75	218.4	974.9	€ 2,184	€ 9,749
99.9 %	4.35	9.59	628.8	1384.4	€ 6,288	€ 13,844

Table 10: Minimum and maximum inventory level per month in cars, square meters and holding costs, project 4.

Data that is more precise is generated by splitting the overall warehouse capacity into its particular warehouse types.

Tables 11 to 13 present the results of optimal minimum and maximum inventory level, required square meters and corresponding holding costs per month for warehouse types A2, B1 and B2. For project 4, only these three warehouse types are relevant, because the material sourced from potential VMI suppliers can only be classified into these types of warehouses. In warehouse type A1 only small and sensitive material is stored, which we did not considered in our data collection.

The results for warehouse type A2, temperate internal block, are:

Service-level α	Min cars	Max cars	Min m²	Max m²	Min Holding costs	Max Holding costs
85 %	1.51	6.75	55	245.3	€ 550	€ 2,453
99.9 %	4.35	9.59	158	348.2	€ 1,580	€ 3,482

Table 11: Minimum and maximum inventory level per month in cars, square meters and holding costs for warehouse type A2, project 4.

The results for warehouse type B1, cold internal pallets, are:

Service-level α	Min cars	Max cars	Min m²	Max m²	Min Holding costs	Max Holding costs
85 %	1.51	6.75	3.4	15.3	€ 34	€ 153
99.9 %	4.35	9.59	9.9	21.8	€ 99	€ 218

Table 12: Minimum and maximum inventory level per month in cars, square meters and holding costs for warehouse type B1, project 4.

The results for warehouse type B2, cold internal block, are:

Service-level α	Min cars	Max cars	Min m²	Max m²	Min Holding costs	Max Holding costs
85 %	1.51	6.75	138.1	616.3	€ 1,381	€ 6,163
99.9 %	4.35	9.59	397	875.2	€ 3,970	€ 8,752

Table 13: Minimum and maximum inventory level per month in cars, square meters and holding costs for warehouse type B2, project 4.

Given these results of all α - service levels for all projects and warehouse types, we now need to choose our target α - service level under the condition that the warehouse space at Plant Vienna is limited.

The following tables summarize the required space of all projects subject to the different warehouse types. In both tables, M^2 represents the maximum storage capacity of each warehouse type. Here, we can see that the required space for warehouse type A2 and B2 exceed the possible capacity for both α - service levels.

With α - service level of 85% we have

Min m²	Max m²	M²	Warehouse type
655.7	2,019.5	1,425	A2
115.2	363.7	1,066	B1
1,405	4,221.2	562	B2

Table 14: Total required minimum and maximum inventory space for α = 0.85.

With a α - service level of 99.9% we have

Min m²	Max m²	M²	Warehouse type
1,885	3,248.9	1,425	A2
331.2	579.7	1,066	B1
4,576	8,373.2	562	B2

Table 15: Total required minimum and maximum inventory space for α = 0.99.

To find a target α - service level under the condition that Plant Vienna has limited storage capacity, we must choose a lower possibility of demand met by stock. Another service level approach might give more precise results, but will not lead to a better or possible solution without reducing the possibility of demand met by stock. To find another solution with this approach, we continue with a trial-and-error procedure.

5.5.2 Service Level Beta

We are still at the same status quo as one subchapter before. Finding ourselves in a situation of continuous replenishment possibilities and the objective to find the optimal minimum and maximum inventory levels, we now try to solve the problem with the $\beta - service\ level$. This service level measures the share of demand, which is not postponed on average. For a periodic inventory management, the exact calculation is difficult. Thus, we will use an approximate solution, where we will estimate how much demand will not be postponed in the previous period (Thonemann, 2010, p. 233 f.). The $\beta - service\ level$ represents the fill rate or material availability for our case (Tempelmeier, 2006, p. 184).
In contrast to the $\alpha - service\ level$ approach, we can not look up the relevant z-values out of the Normal Distribution table. The first step includes the calculation of the z-value:

$$z^* = \frac{(1-\beta)\mu}{\sigma}$$

Formula 7: Calculation of z - statistic for service level beta

Again, we chose a material availability from 85% to 99,9%, in total 32 different β values. The corresponding β values can also be seen in the attached storage medium. Coming from a different evaluation of the z-value, the results for minimum and maximum inventory level in cars, square meters and holding costs will be different. The $\beta - service\ level$ is more sensitive as the $\alpha - service\ level$ and results in lower outcomes. Negative

$\beta - service\ level$ values are ignored in our approach, as negative inventory levels are not possible.

Target stock and safety stock are calculated with the exact same formulas as in 5.4.1.

We will not go into much detail for this approach, but will compare the summarized required space of all projects regarding their corresponding warehouse types.

With a $\beta - service\ level$ of 85% the results are the following:

Min m²	Max m²	M²	Warehouse type
115	1,478.8	1,425	A2
14.9	263.4	1,066	B1
391.4	4,188.7	562	B2

Table 16: Total required minimum and maximum inventory space for $\beta = 0.85$.

With a $\beta - service\ level$ of 99.9 % the results are the following:

Min m²	Max m²	M²	Warehouse type
1,572.7	2,936.5	1,425	A2
274.4	522.9	1,066	B1
4,039.4	6,855.6	562	B2

Table 17: Total required minimum and maximum inventory space for $\beta = 0.99$.

The differences between optimal minimum and maximum inventory level are larger than with the $\alpha - service\ level$. That is, because $\beta - service\ level$ represents only an approximation of demand which is not postponed and the corresponding z – values for each probability in the Standard Normal Distribution table differ more than for $\alpha - service\ level$.

5.6 Service Level Results

Table 14 and 15 for the $\alpha - service\ level$ and table 16 and 17 for the $\beta - service\ level$ show, that warehouse types A2 and B2 are getting exceeded regardless of the chosen service level and desired probability. A 99% probability for $\alpha - service\ level$ and $\beta - service\ level$ is basically impossible for our approach to find the optimal minimum and

maximum inventory levels. With the given μ and especially σ of each project, a 99% probability to either meet demand by stock or material availability leads automatically to extreme high results for minimum and maximum inventory level. Only warehouse type B1, cold internal block warehouse, provides a sufficient solution for the $\alpha - service\ level$ approach of 85% and 99,9% probability. On one hand, this could be, because we did not have much material, which belongs to warehouse type B1. On the other hand, warehouse type B1 provides a lot of storage area and consequently we could find an optimal solution for this warehouse type over all projects. It would be possible to store material which belongs to warehouse types D, C or B in other warehouses, unless restrictions like temperature and required space are satisfied. Material which theoretically belongs to warehouse type B1 could therefore be stored in warehouse type A2, but it is not possible to store material from internal temperate block warehouses in internal pallet types. Nevertheless, this idea would not lead to a better solution in our approach, because the exceeded warehouse types are A2 and B2.
Given the generated data with its output and deviation information of each project, we still strive to find a solution for our situation. One assumption for the service level approach was to set an equal service level across all projects and to not prioritize any project. This idea complies with the actual reality at Plant Vienna, but due to delay or internal business policies, some projects may be considered with a higher priority important during a period than other projects. This idea leads to another approach of finding optimal minimum and maximum inventory levels for Plant Vienna.

5.7 Linear Programming Model

Linear programming is a procedure to optimize the use of scarce resources and can be applied to multiple problems (Thonemann, 2010, p. 569). Common application areas are production, scheduling and network planning. The objective of a Linear Programming (LP) model is either to minimize or maximize the underlying problem. Besides the objective, several constraints need to be defined. These constraints restrict the possible set of solutions, insofar that there should be one optimal solution.
In our case, the corresponding LP-model is:

$$\max \sum_i \gamma_i \sum_j x_{ij}\, \alpha_j$$

subject to

$$x_{ij} = \{0,1\} \qquad \forall\, i,j$$

$$\sum_j x_{ij} = 1 \qquad \forall\, i$$

$$\sum_i \sum_j x_{ij} m_{ij} \leq M$$

Formula 8: LP Model for Maximum Stock

The objective of your problem is to find the optimal probability α that demand is met by stock, over all projects i and chosen service level j. The letter γ represents the prioritization of each project i and must be chosen between 0 and 1. The variable x determines which $\alpha - service\ level$ is chosen j and for each project *i*. The objective function is restricted by three constraints. The first one states, that *x* is a binary variable and can only have the values zero or one. The second constraint determines, that there can only be one target stock j be chosen for each project *i*. The last constraint represents the restricted warehouse capacity. The resulting required capacity of all chosen service levels j of all projects i must be smaller or equal than the maximum capacity of the warehouse type.
This LP model is solved for all three warehouse types and for the $\beta - service\ level$.

Before implementing the LP model into Excel, we need to reduce the number of chosen service level probabilities, as the used Excel version is restricted. We now continue with 18 different probabilities for α and $\beta - service\ level$, with the remaining limitations of 85% and 99.9%. The updated list of α and $\beta - service\ level$ probabilities and their corresponding z-values can be seen in the attached storage medium.

Starting with the $\alpha - service\ level$ approach, we implement the LP model into Excel and solve the problem with the excel solver. The only decision we must make is which γ - value we set for each project. As already mentioned, the γ - value should be between 0 and 1 and the higher the γ - value the more prioritized the project is. Anticipating an invalid solution for warehouse type A2 and B2, we set all projects to a γ - value of 0.1.
In both cases, warehouse type A2 and B2, for no $\alpha - service\ level$ between 85% and 99.9%, a valid solution could be found. Even with different priorities over the projects, the LP model is not able to find a solution. The only warehouse type for which we can state optimal

minimum and maximum inventory level is warehouse type B1, cold internal block. This warehouse type provides a storage area of about 1,066 m² and the maximum space over all products needed with a 99% probability that demand is met by stock is circa 506 m². We can actually set all γ - values to 1 for this warehouse type and still find an optimal solution for this LP model.

The same applies for the $\beta - service\ level$ approach. Warehouse types A2 and B2 are exceeded; respectively there is too much generated data in form of material, which belongs to these warehouse types. Again, warehouse type B1 provides enough space to fulfill the highest probability of material availability as well as the same maximum priority level for all projects at once.

All Excel tables can be seen in the attached storage medium.

5.8 Result

So far, we could not find an overall optimal solution for minimum and maximum inventory level of all warehouse types for all projects. The storage area of warehouse type A2, temperate internal block, and type B2, cold internal block is too small for the data we generated from the potential VMI suppliers. Only warehouse type B1, cold internal pallet, provides enough space for both approaches, a satisfying high probability that demand is met by stock and material availability and simultaneously not prioritizing any project.

As already mentioned, one reason could be the amount of data that was generated. We selected 28 suppliers in a previous analysis. The total number of suppliers for Plant Vienna is more than 500. Therefore, the potential VMI suppliers represent just a small fraction and due to basic situation, the number of VMI supplies should not be reduced. The same applies for the material we considered. In this approach, only information about material of great dimensions was collected. We ignored the fact that some potential VMI suppliers provide a broad portfolio of material and we only considered relevant material for our VMI approach.

One reason, why there is no optimal solution is the determination of mean car production per month μ for each project and the resulting standard deviation σ. Both values were calculated over the whole project duration. This leads to an inaccurate further calculation for the required safety and target stock. Project 1a and 5 show an extreme value for their standard deviation. A potential opportunity to gain more precise results is to observe not the whole project duration, but a period of about 3 or 4 months, in which μ and σ should be calculated again. This would result into a bigger effort, but the optimal minimum and maximum

inventory levels should be adjusted in regular intervals as well. Project delays or increases in production output, here to be understood as cars produced per month, would be included in the regular calculation. Within the VMI portal and the provided forecast, the supplier would get informed about any production changes in advance. Any adjustments concerning the minimum and maximum inventory level need to be communicated with the supplier periodically. In sum, instead of observing the whole project duration, the duration should be split up into periods of 3 to 4 months in which the optimal minimum and maximum inventory level are calculated. This updated information has to be communicated with the supplier and the forecast data needs to be adjusted.
Another reason is the limited storage capacity at Plant Vienna. Even though this might seem as a simple suggestion for our problem, both approaches, service level and LP model, showed that we would exceed warehouse type A2 and B2 but not B1. The site of Plant Vienna cannot be expanded and within the plant, all areas are fully used either as warehouses, factory buildings or offices. Nevertheless, a restructuring of the warehouse types seems possible. The solution showed, that warehouse types A2 and B2 are required most. Logical consequence would be, to provide more temperate internal and cold internal block warehouses and reduce other warehouse types, which are not required for VMI material in the same way. We only considered VMI potential suppliers and material in our inventory calculation. The existing warehouses provide space for all material, independently of VMI or CW concept. Therefore, we do not know if the warehouse areas, which are not used in our approach, are actually vacant. In general, and from our own experience, warehouse types A and B are completely used. A restructuring, to change from pallet to block, is not possible. This leads to the only possible solution; to rebuild warehouse types C and D to the required types. An exact data generation and analysis about all warehouse types at Plant Vienna and the corresponding material for each warehouse type is needed. Thereinafter, investments and a fundamental restructuring of the warehouse areas would possibly lead to a better solution.

In order to maintain its success in the market and secure its position in the long term, Siemens AG Austria needs to optimize its supply chain and adjust its business model to the market. There are many indications that SAG Austria should and will focus on its core competency; manufacturing trains. Instead of restructuring warehouses at Plant Vienna and change inventory management, one relevant possibility would be to outsource the whole department of inventory management. Role model for this would be Plant Krefeld, which already collaborates with a third party logistics service provider. Plant Krefeld rents its warehouses and inventory locations to a service provider, who is responsible for all warehouse management activities, among other things like VMI and CW concepts.

A collaborative partnership with a third-party logistics service provider seems like the most possible and realistic solution to overcome internal weakness for Siemens AG Austria and Plant Vienna and find a way back to efficient and effective project business in the rail industry.

6 Delivery Combination

The second part of this master thesis will focus on the deliveries from the potential VMI suppliers, considered in the first part, to Plant Vienna. We will try to find a saving by combining single deliveries of the VMI suppliers based on the Vehicle Routing Problem. On condition that the deliveries should be shipped in a specific period of time, we selected 9 weeks where we try to combine deliveries in each week. Depending on the loading meter of each shipment, the combined shipments should not exceed the maximum capacity of 13.6 loading meter in a truck.

The second part of this master thesis will give a quick introduction in the delivery process at Plant Vienna and the data collection, an explanation of the saving algorithm and its implementation and finally an analysis of the results.

6.1 Deliveries to Plant Vienna

Depending on the 'Incoterm', International Commercial Term, Siemens or the supplier bears costs and responsibility for the shipment. In general, there are two main Incoterms applied between Siemens and their suppliers. The preferred Incoterm is 'FCA', Free Carrier, where Siemens picks up the shipment from the suppliers' side and takes over costs and risk for the shipment. In some cases, 'DAP', Delivered At Place, is applied, where the supplier delivers the shipment to the plant and takes over costs and risk. We will consider only suppliers with Incoterm FCA, as we are trying to optimize delivery costs beard by Siemens.

Before a delivery is shipped, the supplier must announce the shipment via an order tool. Required data are address, pick up date, delivery date, dimensions and weight of the shipment, which must be typed in the order tool. After the supplier finished the input, the order tool selects a suitable carrier and hands over the delivery order to the carrier. The order tool documents all announced deliveries, information and costs of each shipment to Plant Vienna. Therefore, the order tool is a software solution not only used by the FCA suppliers but is also an interface with the carriers. The carrier determines the conditions of the shipment, routing and loading. Therefore, the carrier combines deliveries to its benefit and pools different deliveries from different customers together. In general, Siemens cannot directly influence the delivery. The costs for a shipment depends on the market price as well as the delivered distance, weight and size of the delivered good. Special transports, like an express delivery or oversized goods are handled and offset differently and will not be considered in our approach.

Figure 8 shows a map of central Europe to provide a general idea where the suppliers are located and about the distance between suppliers to each other and Plant Vienna.

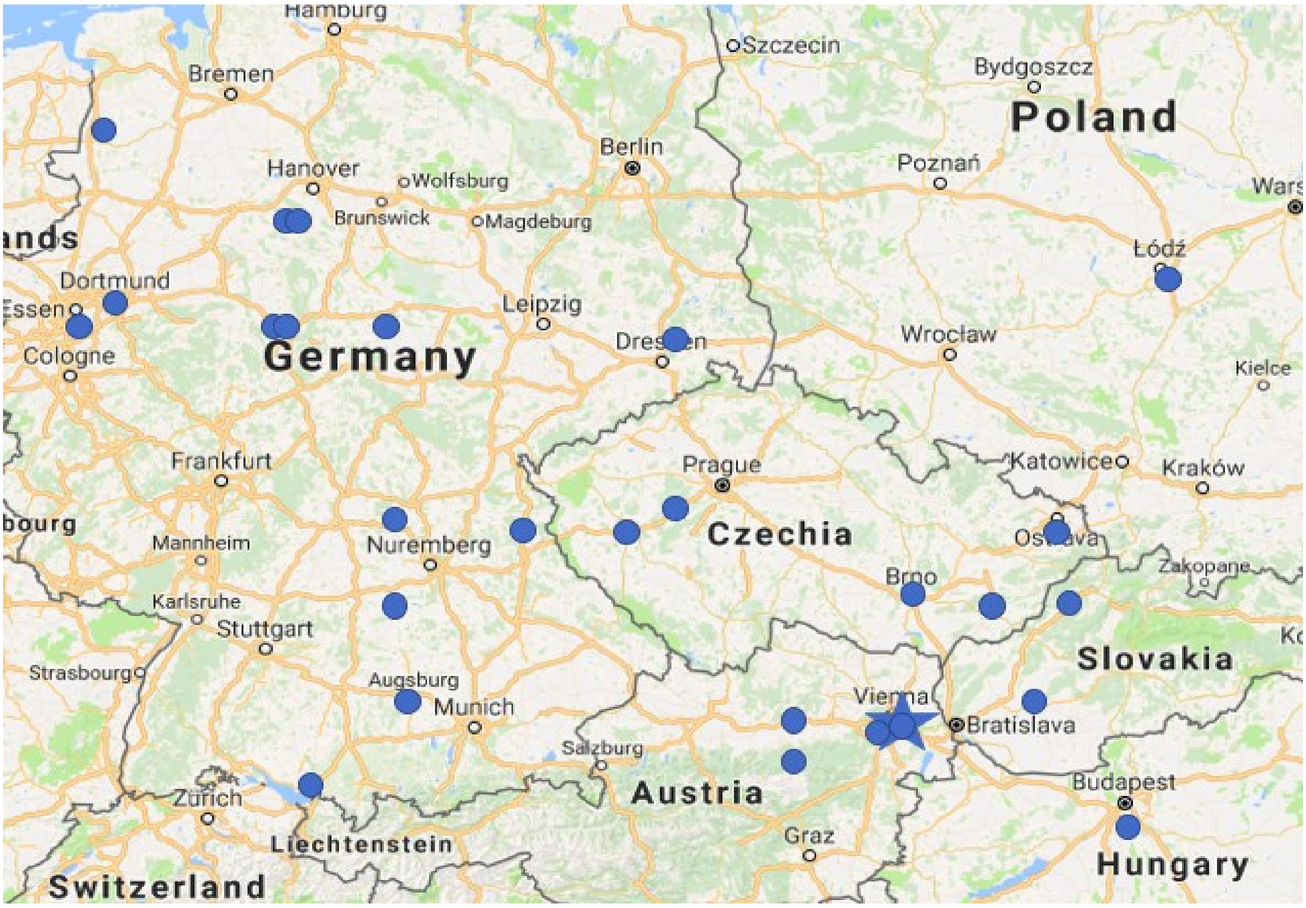

Figure 8: Location Map potential VMI suppliers and Plant Vienna. Source: Google Maps.

The map section shows that the potential VMI suppliers or their production sites are mainly located in Austria, Germany and the Czech Republic. A few are located in Slovakia, Hungary, Poland and Italy.

As transportation mode for our selection of potential VMI suppliers, exclusively trucks are used, because no river or sea needs to be traversed, the infrastructure in this catchment area is well developed and they provide maximum flexibility. The largest distance between a supplier and Plant Vienna is about 1,070 kilometers and between two suppliers is about 1,250 kilometers.

6.2 Data Collection

For our approach, we considered all deliveries during the time horizon from October 2016 to June 2017. With the unique identification number of each potential VMI supplier, we could access all deliveries using the order tool. To reduce the amount of data, we chose one week per month of the time horizon from October 2016 to June 2017. The output is complex excel files and each delivery information consists of 22 specific partial information. Table 18 gives a simplified impression about the delivery data.

Delivery Date	Forwarder	Country Code	Supplier	Order Number	Country of Lading	Country of Delivery	Quantity	Weight	Loading Meter
01.10.2016	ABC	D > AT	1	12345	D	AT	3	250	2.38

Table 18: Data Collection Part II

Most of the data is not necessary for our approach, so we reduced the amount of data again resulting in a table of two columns. Table 19 only shows the supplier number and the loading meter required for the delivery. We created an excel file for each selected week over the time horizon from October 2016 to June 2017. All delivery input files of each week are available on the storage medium.

Supplier	Loading Meter
4	0.5
9	1.14
11	1.08
11	1.29
15	13.6
16	2.95
28	0.82

Table 18: Reduced Data for implementation.

Based on the saving algorithm we want to implement, we need additional data about the initial costs of the single deliveries from each potential VMI supplier to Plant Vienna. Here, we used the output from the order tool and derived average fixed costs of € 170.00 per delivery and average variable costs of € 1.10 per kilometer.

Basis for the delivery combination is the distance Matrix we created. With 28 potential VMI suppliers, we need the distance between each supplier and Plant Vienna. The distance matrix was created with the Microsoft MapPoint 2013 program with its Plug-In MPMileCharter. Necessary data for the MapPoint program are Longitude and Latitude information of each location, in our case, the warehouse of each supplier and Plant Vienna.

Supplier	Longitude	Latitude
1	5213XXXX	1041XXXX
2	5128XXXX	951XXXX
3	4811XXXX	1490XXXX
4	4896XXXX	1817XXXX

Table 19: Longitude and Latitude for MapPoint 2013.

Using this data, we developed a saving algorithm based on the Clarke and Wright saving algorithm, which is one of the most known heuristic for 'Vehicle Routing Problems' (VRP).

6.3 Vehicle Routing Problem

In the classic 'Vehicle Routing Problem', starting from the depot goods must be delivered in given quantities to given customers. To transport the goods several vehicles are available, each with a certain capacity. Each vehicle applied in the solution must cover a route on which goods are delivered to one or more customers, starting and ending at the depot (Lysgaard, 1997, p. 1). The objective of the classic vehicle routing problem is to find a route at a minimal cost, fulfilling demand of all visited nodes with start and end at the depot. The graph in figure 9 below shows a simplified representation of two routes. Both routes start from the depot, which is the blue node, and serve each customer once.

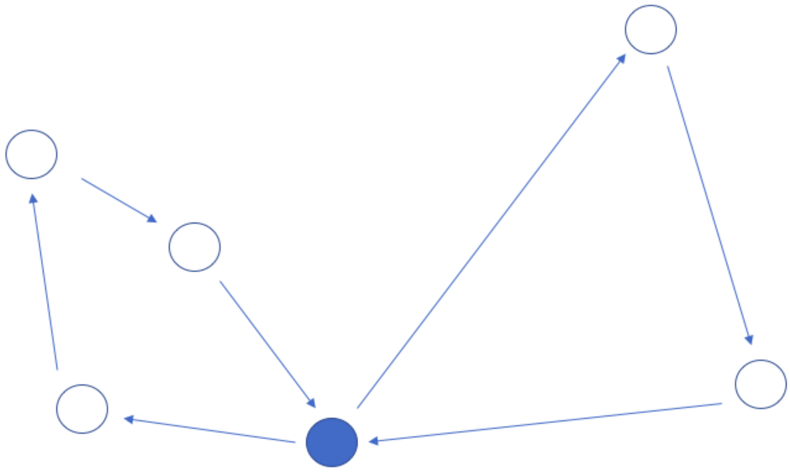

Figure 9: Route example.

Type of costs can vary from finding the shortest path to minimize the number of vehicles used. Each node in a route is visited only once, by one vehicle with restricted capacity. There exist many extensions of the 'Vehicle Routing Problem', like the VRP with Time Windows, Split Deliveries or Pickup and Delivery (Belfiore, Tsugunobu, & Yoshizaki, 2008, p. 1 ff.). Other constraints are the number of vehicles used, duration of any route or serving of customers within pre-established time windows (Gjiani, Laporte, & Musmanno, 2013, p. 359 ff.). The Vehicle Routing Problem is one of the most important and studied combinatorial optimization problem. In 1959 Dantzig and Ramser introduced a real-world application of the VRP concerning the delivery of gasoline to service stations. They proposed the first mathematical programming formulation and algorithmic approach. (Toth & Vigo, 2002, p. xvii).

There are three different basic modelling VRP approaches proposed in the literature. The first type is known as 'Vehicle Flow Formulation' and uses integer variables, associated with each arc or edge of the graph counting the number of times the arc or edge is traversed by a vehicle. This type is frequently used as a model for basic versions of VRP and are best suited for problems, where the cost of the solution can be calculated as the sum of the costs associated with the arcs. The second and third type are the 'Commodity Flow Formulation' and 'Set-Partitioning-Problem'. The former is used only recently for exact solutions for the 'Capacitated VRP' (CVRP). The latter provides an exponential number of binary variables and produces a formulation whose linear programming relaxation is typically much tighter than that in the previous model types (Toth & Vigo, 2002, p. 11).

We will continue with the 'Vehicle Flow Formulation'. This basic mathematical model for the VRP uses an integer programming formulation, with a two-index vehicle flow formulation that uses $O(n^2)$ binary variables x, which imply whether a vehicle traverses an arc in the optimal solution or not. Therefore, variable x takes value 1 if arc $(i,j) \in A$ is in the optimal solution or takes value 0 otherwise (ibid).

The objective function of the basic CVRP is:

$$\min \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}$$

Aim is to minimize the travel cost c going from vertex i to vertex j. Let $G = (V, A)$ be a complete graph, where $V = \{0, \dots, n\}$ is the vertex set and correspond to the customers, while vertex 0 would be the depot, and A is the arc set. In case the vehicle traverses the arc between i and j, the binary variable x takes the value 1 and will be multiplied with the corresponding cost of vertex i to j.

Constraints of the basic CVRP are:

$$\sum_{i \in V} x_{ij} = 1 \quad \forall j \in V \setminus \{0\}$$

$$\sum_{j \in V} x_{ij} = 1 \quad \forall i \in V \ \{0\}$$

$$\sum_{i \in V} x_{i0} = K$$

$$\sum_{j \in V} x_{0j} = K$$

$$\sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S) \ \forall S \subseteq V \setminus \{0\}, S \neq \emptyset$$

$$x_{ij} \in \{0,1\} \forall i,j \ \in V$$

Formula 9: LP model for the CVRP. Source: (Toth & Vigo, 2002, p.12).

The first two constraints, the indegree and outdegree constraints, determine that exactly one arc enters and leaves each vertex associated with a customer respectively. The following two constrains, say that the number of vehicles leaving the depot is the same number entering.

These two and following constraint are the capacity cut constraints and impose that all routes must be connected and demand must be smaller or equal than the vehicle capacity.

For our problem, we need to extend the CVRP to a few constraints. We also want to implement a transportation network, where Siemens picks up material from multiple VMI suppliers and delivers directly to the plant.

6.3.1 Direct Shipments with Milk Runs

Supply chain performance is strongly influenced by the design of the transportation network. Operational transportation decisions regarding scheduling and routing establish the infrastructure and a high degree of responsiveness is achieved when the transportation network is well designed. In our approach, we strive to optimize transportation costs by combining deliveries of the VMI suppliers. The most suitable option of a transportation network design for our case is 'Direct Shipping With Milk Runs'. In general, a milk run is a route on which a vehicle either delivers products from a single supplier to multiple buyers or delivers from multiple suppliers to one single buyer. The latter is relevant for our case. In an environment of direct shipping with milk runs, a truck picks up deliveries destined for the same buyer from many suppliers, which can be seen in figure 10 (Chopra & Meindl, 2016, p. 421 f.). Based on this, we want to decide on the routing of each milk run.

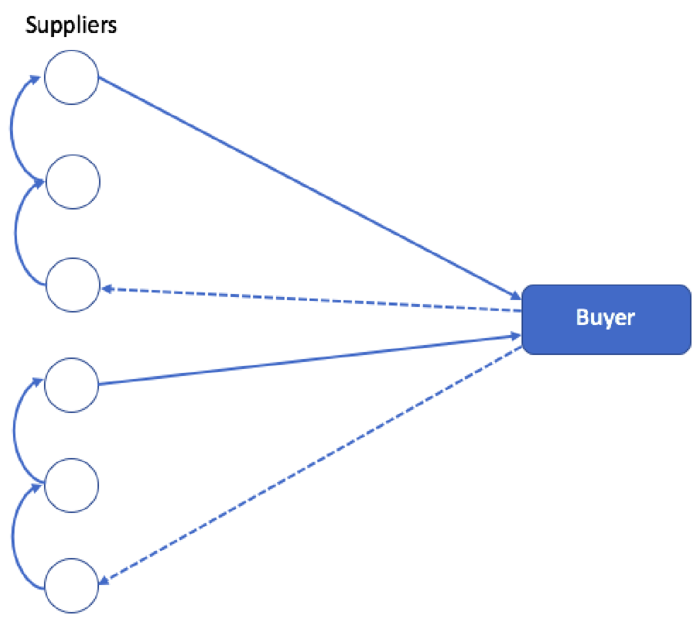

Figure 10: Direct Shipment with Milk Runs. Source: Own figure based on (Chopra & Meindl, 2016).

Deliveries from suppliers to Plant Vienna are performed by third party carrier, who combine shipments depending on their orders and capacity. The bundling of deliveries allows the carrier a great scope to minimize transportation costs while combining deliveries independently of their customers. In our approach, we consider only deliveries from the potential VMI suppliers during the period from October 2016 to June 2017. We selected nine weeks, where we try to optimize transportation costs, by combining the deliveries of all potential VMI suppliers during one week. Fixed costs per delivery and variable costs per kilometer are known as well as the loading meter of each planned delivery. This is done based on the savings algorithm by Clarke and Wright.

6.3.2 Saving Algorithm

The savings algorithm is an iterative procedure that initially generates an amount of distinct routes each of which serves a single customer. This heuristic algorithm does not provide an optimal solution to the problem with certainty. At each subsequent iteration, the heuristic tries to merge a pair of routes striving to create a cost reduction, which we call *a saving*. The basic savings concept is illustrated in figure 11, where two routes are joined into one route.

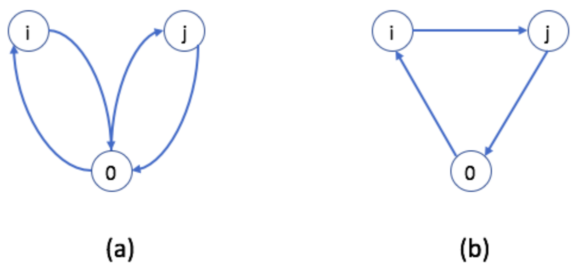

Figure 11: Clarke and Wright Saving Algorithm. Source: Own figure based on (Lysgaard, 1997).

Point 0 represents the depot, from which in figure (a) two routes visit customer i and j separately. An alternative is shown in figure (b), where both customers are visited in one route, in a sequence $i-j$.

Transportation costs of each route are given and we can calculate the savings resulting from driving route (b) instead of both routes in (a). When traveling from customer i to customer j costs c_{ij}, total transportation costs D_a in figure (a) are:

$$D_a = c_{0i} + c_{i0} + c_{0j} + c_{j0}$$

Total transportation costs D_b in figure (b) are:

$$D_b = c_{0i} + c_{ij} + c_{j0}$$

The saving S_{ij} is created when combining the two routes:

$$S_{ij} = D_a - D_b = c_{0i} + c_{0j} - c_{ij}$$

In case S_{ij} is relatively large, with regards to costs, it indicates to visit customer i and j on the same route such that customer j is visited immediately after visiting customer i.

The first step of the savings algorithm includes the calculation of the savings for all pairs of customers. These savings are sorted in descending order, which implies that the saving with the highest value is considered first. Starting with the first pair of customers $i - j$, the two routes from i to j are combined, taking into account the previously established direct connection between to customers and total demand of the combined tour does not exceed the vehicle capacity (Lysgaard, 1997, p. 2).

There are two versions of the savings algorithm, the sequential and the parallel version. The former builds exactly one route at a time, while the latter may build more than one route at a time (Lysgaard, 1997, p. 3).

In our approach, we neither have routes illustrated in figure 10, as we only consider deliveries starting from each supplier to the plant. Our savings approach is shown in figure 12, where we can see that in figure (c) we only have direct shipments. Return deliveries, e.g. returnable rack circulation, are not considered in this master thesis, but deserve further research and calculation. Figure (d) illustrates direct shipping with milk run, because the truck visits supplier i before j when travelling to Plant Vienna.

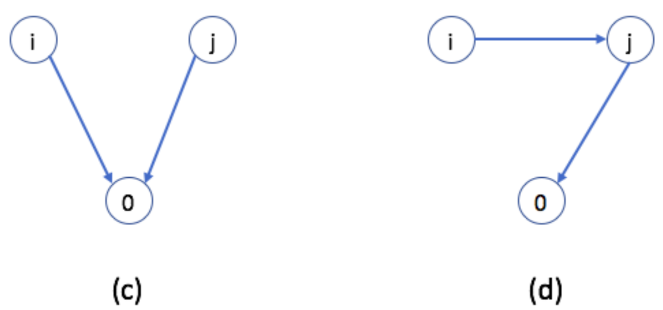

Figure 12: Siemens Saving Algorithm.

Total transportation costs D_c of figure (c) are:

$$D_c = c_{i0} + c_{j0}$$

Total transportation costs D_d of figure (d) are:

$$D_d = c_{ij} + c_{j0}$$

The combination of the two separate tours in figure (c) do not automatically imply a saving. Our saving $S_{ij}$is created when combining D_c and D_d:

$$S_{ij} = D_c - D_d = c_{i0} - c_{ij}$$

Another characteristic of Siemens saving algorithm is that there could be multiple deliveries from one supplier within one week, which can be seen in table 19. The Siemens saving algorithm should consider not only route combination between different suppliers, but also the bundling of deliveries from the same supplier.

6.4 Implementation

For the implementation, we used Xcode 9.0 on a MacBook air, 1.8GHz dual-core Intel Core i5 with 3MB shared L3 cache. Xcode is an integrated development environment for macOS. The input files, which are distance matrix and deliveries per week, are in .txt and .csv format and can be accessed on the storage medium attached. The first two steps include the reading of both input files per saving run. That means, that for each month new savings will be calculated, based in the input from the specific deliveries in this week, and compared with the initial costs from the order tool and the initial costs calculated with the average fixed and variable costs of € 170.00 and € 1.1 per kilometer. The following step already calculates the savings occurring from the deliveries in one week. The amount of savings varies, because the amount of deliveries per month vary between 13 deliveries in November deliveries and 55 deliveries in March. Therefore, the amount of savings equals the amount of deliveries plus 1 to the power of two, which results in 3,136 savings for week 7 in March. The last step iteratively combines the single tours into and calculates the sum of all tour costs. For the tour combination, we only consider savings with a positive value. For each saving, performed saving, as the combination of two deliveries, the remaining capacity, the used capacity, the tour costs and the included deliveries of each route are calculated as well as the total cost of all tours per week.

To show how the code and saving algorithm works, we will have a closer look at one example. Week 2 in November provides 13 deliveries from potential VMI suppliers to Plant Vienna. The corresponding supplier number and the required loading meter per shipment can be seen in table 21 below.

Supplier	Loading Meter
4	0.8
5	1.55
5	1.28
2	0.4
2	0.4
25	0.11
20	0.03
17	8
18	0.4
18	0.25
22	3.1
1	0.4
1	5

Table 20: Deliveries Week 2 November.

Resulting from this input, we receive 169 saving values. The scope of the saving values goes from € 1,061.08 as the highest to € 655.447 as the lowest. The lowest positive saving is € 2,699. The first step is to calculate the initial single routes for each delivery. Supplier 1, 2, 5 and 18 have more than one delivery in this week, but their deliveries are considered separately. Therefore, we have 13 shipments from the suppliers to Plant Vienna and resulting total cost of € 10,718.8 for this week in November 2016. Following the saving approach, the algorithm starts with the highest saving and tries to combine the two nodes which created the saving. If the combination of both deliveries is stored in the structure *NodePair* as *node1* and *node2,* it is not a 'fake' saving value and the combination does not exceed the maximum capacity of the truck, both deliveries are combined. In our example, the two deliveries of supplier 5 are combined and the new total cost of all 12 deliveries are the difference between the total cost of the initial solution and the saving from both deliveries of supplier 5; € 9,657.

```
Performed saving 5 - 5

Remaining capacity: 12.8    Used capacity: 0.8  Costs: 407.791
4
Remaining capacity: 10.77   Used capacity: 2.83 Costs: 1061.08
5   5
Remaining capacity: 13.2    Used capacity: 0.4  Costs: 1058.61
2
Remaining capacity: 13.2    Used capacity: 0.4  Costs: 1058.61
2
Remaining capacity: 13.49   Used capacity: 0.11 Costs: 721.298
25
Remaining capacity: 13.57   Used capacity: 0.0299997    Costs: 354.318
20
Remaining capacity: 5.6 Used capacity: 8    Costs: 343.263
17
Remaining capacity: 13.2    Used capacity: 0.4  Costs: 1035.8
18
Remaining capacity: 13.35   Used capacity: 0.25 Costs: 1035.8
18
Remaining capacity: 10.5    Used capacity: 3.1  Costs: 472.095
22
Remaining capacity: 13.2    Used capacity: 0.4  Costs: 1054.52
1
Remaining capacity: 8.6 Used capacity: 5    Costs: 1054.52
1
Total costs of the solution: 9657.7

Our saving was : 1061.08
```

The whole saving algorithm is iterated for ten times until there are three routes left and no more saving is possible. The first route includes suppliers 25, 18, 2, 5, and 1. The route starts at supplier 1 where two deliveries are combined and continues to supplier 2, 5 and 18 which also have two deliveries in this week. The last stop is at supplier 25 with one delivery before arriving at Plant Vienna. The overall cost of this route is € 1,311.56. The second route only includes three suppliers. Starting from supplier 22 to supplier 4 costs € 154.44 and from supplier 4 to supplier 20 costs € 124.52. The last part from supplier 22 to Plant Vienna costs € 184.32. Total costs, including fixed costs, result in € 633.28 for the whole route. This combined tour uses only 3.93 of 13.6 loading meter of the truck, whereas the first route nearly uses the whole truck with 9.79 loading meter. The last route in this week is from supplier 17 to Plant Vienna. Here, the delivery requires relatively much space in the truck with 8 loading meter. The costs for this single delivery are € 173.26. The sum of all three routes in this week are € 2,288.1, which is about one fourth of the initial solution without implementing the saving algorithm.

```
Remaining capacity: 3.81    Used capacity: 9.79 Costs: 1311.56
25  18  18  2   2   5   5   1   1
    Base costs: 170
    Costs from 25 to the final destination: 551.298
    Costs from 18 to 25: 329.255
    Costs from 2 to 18: 109.428
    Costs from 5 to 2: 3.476
    Costs from 1 to 5: 148.104
Remaining capacity: 9.67    Used capacity: 3.93 Costs: 633.28
20  4   22
    Base costs: 170
    Costs from 20 to the final destination: 184.318
    Costs from 4 to 20: 124.521
    Costs from 22 to 4: 154.441
Remaining capacity: 5.6 Used capacity: 8    Costs: 343.263
17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Total costs of the solution: 2288.1
```

From the input of the order tool, we could sum up the individual costs of the three combined tours and compare them with the costs of the saving approach. Table 22 shows the tours, the potential results from the order tool and the actual results from the saving algorithm. In two out of three cases, the Siemens saving got a better result than the potential order tool result. For the first tour both results are at about the same level. The total transportation costs from the order tool are € 2,548.17 and from the Siemens saving € 2,288.10. Therefore, we achieved our objective to optimize the delivery costs of the potential VMI suppliers for this week in November. The third tour shows the inaccuracy of our approach. The transportation costs from supplier 17 to Plant Vienna are € 161.72 based on the order tool, which is less than our fixed costs we used for the Siemens Saving. As already mentioned, the fixed cost is an average of all deliveries we considered. Therefore, there are several actual transportation costs from the order tool which are less or equal than € 170.00 for a single delivery.

Tours	Order Tool	Siemens Saving
1 – 1 – 5 – 5 – 2 – 2- 18 – 18 – 25 - 0	€ 1,286.14	€ 1,311.56
22 – 4 – 20 – 0	€ 1,100.31	€ 633.28
17 – 0	€ 161.72	€ 343.26
TOTAL	€ 2,548.17	€ 2,288.10

Table 21: Results Week 2 November.

We used this code for every week to calculate the savings and combine the tours to see if the saving algorithm optimizes transportation costs for Siemens AG Austria.

6.5 Result

We did not only find an improvement for week 2 in November, but we could find a better solution using the Siemens saving delivery combination for every of the nine weeks.

Table 23 shows an overview of all nine weeks and the sum of all deliveries from the order tool and the Siemens saving. Here, we can see that the Siemens saving provides a better solution for every week. In week 1 and week 2 the optimization is relatively small, whereas the differences between order tool and Siemen saving become larger, the higher the total costs of the order tool are. Week 4 and especially week 6 show big differences between order tool solution and the Siemens saving solution. Cause for this are on the one hand the calculation of the transportation costs. We used a simplified method and only considered the distance between supplier and Plant Vienna. In reality, loading meter, packaging material and the daily market price determine the transportation costs. On the other hand, there a several special transports, which generate extreme high transportation costs. In our approach, we could not distinguish between special transports, even though some deliveries required trucks, which allow sideway unloading, were not stackable or needed express shipping. Nevertheless, we used average fixed and variable costs based on the order tool data. Total transportation costs from the order tool data are € 93,707.84, whereas total transportation costs after implementing the Siemens saving are € 55,065.55. The reduction of transportation costs is nearly € 39,000.00.

Week	Order Tool	Siemens Saving
Week 1: October 2016	€ 3,840.36	€ 3,099.99
Week 2: November 2016	€ 2,548.17	€ 2,288.10
Week 3: December 2016	€ 7,461.03	€ 3,851.88
Week 4: January 2017	€ 13,304.50	€ 4,660.57
Week 5: February 2017	€ 14,127.54	€ 7,149.16
Week 6: March 2017	€ 19,230.14	€ 9,273.63
Week 7: April 2017	€ 10,845.87	€ 7,229.11
Week 8: May 2017	€ 12,010.44	€ 7,645.02
Week 9: June 2017	€ 10,330.79	€ 6,251.33
TOTAL	€ 93,707.84	€ 55,065.55

Table 22: Results all weeks.

Next to the cost optimization, the resulting routes show that combination of the deliveries are optimized, too. Returning to our example in the subchapters before, week 2 in November provides three tours, in which deliveries from the same suppliers and suppliers which are in a geographic proximity to each other are combined. The combined tours show that no detours were calculated with the optimization. Figure 13 illustrates, that deliveries from supplier 1, 5, 2, and 18 are together in route 1. The route starts at supplier 1, which is located in the northern part of Germany and travels south. Supplier 5 and 2 are located in the same city and supplier 18 is next to supplier 5 and 2. Before arriving at Plant Vienna, supplier 25 is visited, which is located in the northern Bavaria. The second route in week 2 starts in the east of the Czech Republic at supplier 22 and travels through Slovakia, visiting supplier 4 and 20 before arriving at Plant Vienna. Route 3 includes only one delivery from a supplier in Austria.

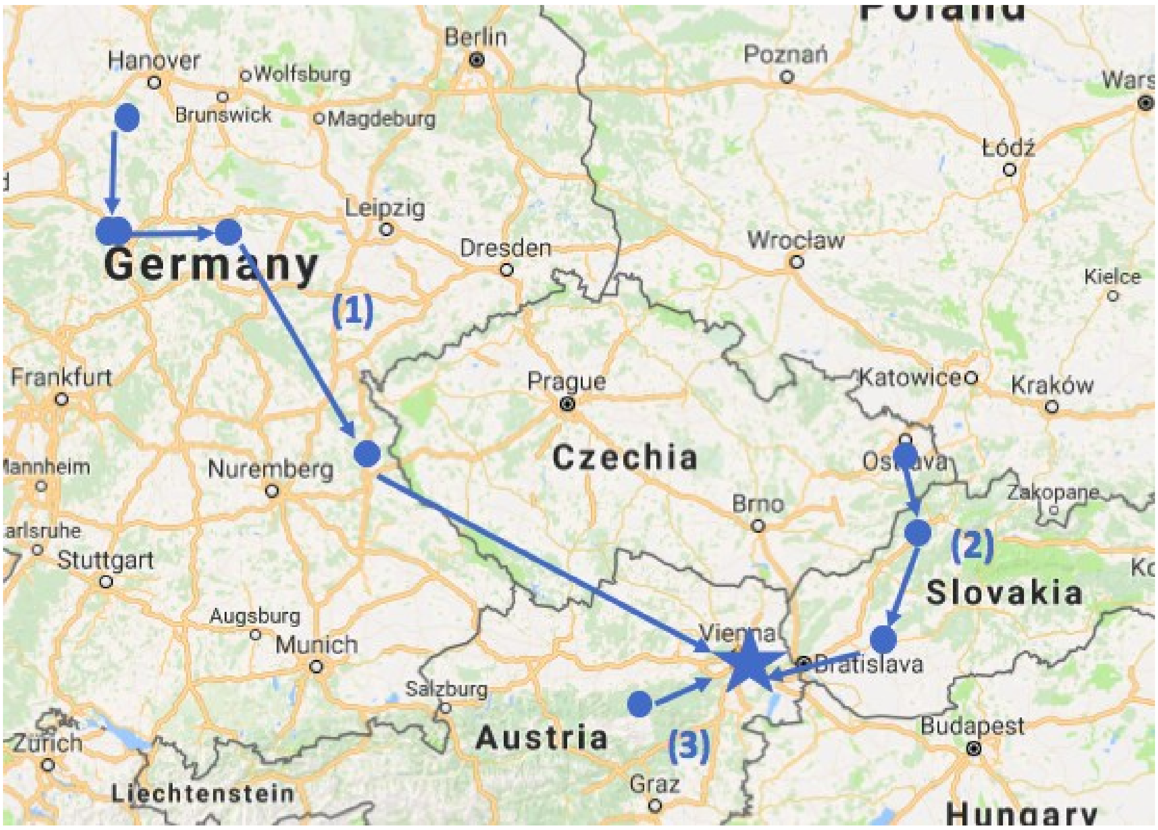

Figure 13: Routes week 2 November. Source: Own figure based on Google Maps.

In our approach, we combined tours within one week. A realistic implementation of this idea is questionable. The VMI concept is based on flexible and supplier coordinated and determined deliveries. Depending on the demand and production cycle at Plant Vienna, the time range of one week might be too long. Penalty costs occur when the inventory is below or above the fixed minimum and maximum levels. Therefore, delivery timing can be very sensitive. Suppliers might adjust their production based on demand and inventory stock. For the potential VMI suppliers, two days are planned as delivery time at the time the shipment is picked up at the supplier to the time the shipment arrives at Plant Vienna. Our approach combined deliveries from the first to the last day in one week, within a range of 5 working days. With the condition that inventory levels must be within the minimum and maximum levels and the two days for delivery, delivery preparation, incoming goods inspection, delay and the bundling within a week, the combination of deliveries in a range of five working days thus tends to be unrealistic. In our simplified approach, we were able to find high savings by implementing the Siemens saving. Table 23 shows the great differences between the actual delivery costs without VMI delivery combination and the optimized results from the Siemens saving. A more precise combination of deliveries with a range of two to three working days and more potential VMI suppliers would lead to a more feasible solution. The differences between initial costs and Siemens saving costs would not differ in the same dimension as in our approach. Nevertheless, the results show that in-house delivery bundling leads to transportation cost reduction. This approach can also be applied for non-VMI material with fixed order and delivery dates. A fundamental implementation of internal delivery combination by Siemens would require high investments, skilled staff, appropriate software and the commitment of the suppliers. The latter had to cooperate with an additional system and provokes additional costs for the supplier. Not only does an implementation imply investments, research and development for Siemens, but also third party carriers need to be involved. A practical application of the delivery bundling based on the Siemens saving would mean that Siemens provides complete routes and therefore replaces a main task of the carriers. Carriers do not only transport goods from i to j, they also optimize their routes by combining shipments under the conditions of costs and time. It is not without a reason that specialized businesses are operating in the field of transportation.

All results of the saving implementation and the corresponding routes can be seen in the Appendix.

7 Conclusion

This master thesis' objective was to reduce costs by optimizing the warehouse situation and deliveries at Plant Vienna. Both parts of the cost reduction approach were based on the Vendor Managed Inventory concept. Part one dealt with the optimal minimum and maximum inventory levels for a certain selection of material. In addition, part two tried to combine deliveries of the selected material.

To give a detailed overview and understanding of the processes at Siemens AG Austria, this thesis started with a fundamental introduction into supply chain coordination, IT supported procurement logistic concepts, order processes and the current status quo at Plant Vienna. Based on the theoretical concepts of the Newsvendor Model, we determined the average demand and standard deviation of each project currently manufactured at Plant Vienna. Coupled with the concept of the Order-Up-To Inventory Model and a linear programming formulation, we calculated the optimal minimum and maximum inventory levels. Not only for service level Alpha, but also for service level Beta, we were not able to find an optimal solution. Causes for this are inaccurate input data and project-business conditions. The time range is too great, in which the optimal minimum and maximum inventory levels are determined. Likewise, production cycles of the various projects differ greatly, which complicate a constant and smooth delivery organization.

Continuing with the same suppliers, we tried to find a transportation cost reduction in the second part. Here, our approach was built upon the Vehicle Routing Problem and the Clarke and Wright Saving Algorithm. For Plant Vienna, we needed a special version of the Saving Algorithm, because we only considered one-way deliveries from suppliers to Plant Vienna. We combined the idea of direct shipments with milk runs and a saving algorithm and found a better solution for every week we considered. The resulting costs of the route combination differed greatly from the initial costs of the order tool. Again, the reasons are inaccurate data and simplified assumption. Having that said, an intelligent combination of VMI based deliveries would definitely lead to a cost reduction for Siemens AG Austria.

Above all, both attempts to optimize processes and costs for Siemens AG Austria and Plant Vienna will remain in theory and will not be continued. The implementation of changes within a company of the size like Siemens AG requires a lot of time, effort and budget. Inventory and warehouse management will rather be outsourced to a third-party logistics service provider than followed up on by internal developments. Likewise, transportation management is an already established and specialized business. An internal implementation at Siemens AG and Siemens AG Austria is therefore inconvenient. However, the results of this thesis might provide a basis for strategic management decisions regarding Vendor Managed Inventory, warehousing and delivery optimization.

Nonetheless, there is much to gain from the implementation and realization of the concept of Vendor Managed Inventory. Within the right environment and an adequate implementation, it leads to an improved ordering process, collaborative partnership with the supplier, leaner management, and ultimately to an overall cost reduction. Siemens AG Rolling Stock needs to concentrate on its core business; manufacturing trains. One objective must be the optimization of the supply chain. Vendor Managed Inventory should be one lever to achieve this aim.

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9 Appendix

9.1 Results Part II

Week 1, October 2016

```
Remaining capacity: 2.83    Used capacity: 10.77    Costs: 2457.47
4   6   6   6   27  27  27  27  18  1   11  11  11
    Base costs: 170
    Costs from 4 to the final destination: 237.791
    Costs from 6 to 4: 505.424
    Costs from 27 to 6: 326.746
    Costs from 18 to 27: 327.859
    Costs from 1 to 18: 179.817
    Costs from 11 to 1: 357.91
Remaining capacity: 0   Used capacity: 13.6 Costs: 738.665
6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 3.1 Used capacity: 10.5 Costs: 374.766
17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Total costs of the solution: 3570.9
```

Week 2, November 2016

```
Remaining capacity: 3.81    Used capacity: 9.79 Costs: 1519.12
25  18  18  2   2   5   5   1   1
    Base costs: 170
    Costs from 25 to the final destination: 551.298
    Costs from 18 to 25: 329.255
    Costs from 2 to 18: 109.428
    Costs from 5 to 2: 3.476
    Costs from 1 to 5: 148.104
Remaining capacity: 9.67    Used capacity: 3.93 Costs: 717.513
20  4   22
    Base costs: 170
    Costs from 20 to the final destination: 184.318
    Costs from 4 to 20: 124.521
    Costs from 22 to 4: 154.441
Remaining capacity: 5.6 Used capacity: 8    Costs: 374.766
17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Total costs of the solution: 2611.4
```

```
Remaining capacity: 8.55    Used capacity: 5.05 Costs: 619.181
23  23  4   4   4   20  20  20  20  20
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 4 to 23: 84.381
    Costs from 20 to 4: 123.644
Remaining capacity: 3.43    Used capacity: 10.17    Costs: 2023.81
12  14  1   1   16
    Base costs: 170
    Costs from 12 to the final destination: 610.906
    Costs from 14 to 12: 123.684
    Costs from 1 to 14: 512.271
    Costs from 16 to 1: 321.751
Remaining capacity: 1.45    Used capacity: 12.15    Costs: 374.766
17  17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0   Used capacity: 13.6 Costs: 527.022
22
    Base costs: 170
    Costs from 22 to the final destination: 302.095
Remaining capacity: 5.09    Used capacity: 8.51 Costs: 852.894
7   7   27  27  27
    Base costs: 170
    Costs from 7 to the final destination: 18.997
    Costs from 27 to 7: 558.836
Total costs of the solution: 4397.68
```

```
Remaining capacity: 3.74    Used capacity: 9.86 Costs: 853.858
23  23  23  23  23  4   4   20  20  20  20  20  9
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 4 to 23: 84.381
    Costs from 20 to 4: 123.644
    Costs from 9 to 20: 198.573
Remaining capacity: 0   Used capacity: 13.6 Costs: 738.665
6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 0.149999    Used capacity: 13.45    Costs: 2235.01
12  1   1   1   1   1   1   1   1   18  18  18  18  18  2   5   11  11  11  16
    Base costs: 170
    Costs from 12 to the final destination: 610.906
    Costs from 1 to 12: 433.071
    Costs from 18 to 1: 179.324
    Costs from 2 to 18: 109.428
    Costs from 5 to 2: 3.476
    Costs from 11 to 5: 245.554
    Costs from 16 to 11: 165.553
Remaining capacity: 1.95    Used capacity: 11.65    Costs: 1151.11
15  6   6   6   6   27  27  27  27  27
    Base costs: 170
    Costs from 15 to the final destination: 408.191
    Costs from 6 to 15: 95.2292
    Costs from 27 to 6: 326.746
Remaining capacity: 2.1 Used capacity: 11.5 Costs: 374.766
17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Total costs of the solution: 5353.4
```

```
Remaining capacity: 7.9 Used capacity: 5.7  Costs: 619.181
23  4   4   4   4   20  20  20  20
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 4 to 23: 84.381
    Costs from 20 to 4: 123.644
Remaining capacity: 5.64    Used capacity: 7.96 Costs: 1252.61
6   6   6   18  18  18  18  18  18  18  18  18
    Base costs: 170
    Costs from 6 to the final destination: 481.178
    Costs from 18 to 6: 434.878
Remaining capacity: 1.61    Used capacity: 11.99    Costs: 1671.96
21  11  11  16  16
    Base costs: 170
    Costs from 21 to the final destination: 1056.57
    Costs from 11 to 21: 48.763
    Costs from 16 to 11: 165.553
Remaining capacity: 0.850001    Used capacity: 12.75    Costs: 1232.93
12  2   2   2   2   2   2   2   2   5   5   5
    Base costs: 170
    Costs from 12 to the final destination: 610.906
    Costs from 2 to 12: 285.022
    Costs from 5 to 2: 3.476
Remaining capacity: 3.2 Used capacity: 10.4 Costs: 1007.16
17  14
    Base costs: 170
    Costs from 17 to the final destination: 173.263
    Costs from 14 to 17: 535.103
Remaining capacity: 1.99    Used capacity: 11.61    Costs: 1595.9
1   1   1   1   1   8   16
    Base costs: 170
    Costs from 1 to the final destination: 884.515
    Costs from 8 to 1: 0.451
    Costs from 16 to 8: 321.564
Remaining capacity: 0.59    Used capacity: 13.01    Costs: 852.894
7   27  27  27  27  27  27
    Base costs: 170
    Costs from 7 to the final destination: 18.997
    Costs from 27 to 7: 558.836
Total costs of the solution: 8232.64
```

```
Remaining capacity: 1.94    Used capacity: 11.66    Costs: 518.78
23  23  22
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 22 to 23: 123.07
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 2.12    Used capacity: 11.48    Costs: 1386.04
6   6   6   6   6   6   6   6   18  2   5   5   5   5   5   5   5   5   5   5
    Base costs: 170
    Costs from 6 to the final destination: 481.178
    Costs from 18 to 6: 434.878
    Costs from 2 to 18: 109.428
    Costs from 5 to 2: 3.476
Remaining capacity: 0   Used capacity: 13.6 Costs: 738.665
6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 3.9 Used capacity: 9.7  Costs: 1645.09
11  11  11  16
    Base costs: 170
    Costs from 11 to the final destination: 1082.6
    Costs from 16 to 11: 165.553
Remaining capacity: 2.53    Used capacity: 11.07    Costs: 374.766
17  17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0   Used capacity: 13.6 Costs: 374.766
17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0   Used capacity: 13.6 Costs: 497.187
9
    Base costs: 170
    Costs from 9 to the final destination: 276.85
Remaining capacity: 0.730001    Used capacity: 12.87    Costs: 1951.91
9   20  20  20  20  4   4   4   1   1
    Base costs: 170
    Costs from 9 to the final destination: 276.85
    Costs from 20 to 9: 197.638
    Costs from 4 to 20: 124.521
    Costs from 1 to 4: 908.761
Remaining capacity: 6.54    Used capacity: 7.06 Costs: 391.602
3   3   3   3   17
    Base costs: 170
    Costs from 3 to the final destination: 150.78
    Costs from 17 to 3: 36.729
Remaining capacity: 3.09    Used capacity: 10.51    Costs: 852.894
7   7   27  27  27  27
    Base costs: 170
    Costs from 7 to the final destination: 18.997
    Costs from 27 to 7: 558.836
Total costs of the solution: 10588.8
```

```
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0.130001    Used capacity: 13.47    Costs: 738.665
6   6   6   6   6   6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 1.57    Used capacity: 12.03    Costs: 850.268
27  27  27  27  27  27  27
    Base costs: 170
    Costs from 27 to the final destination: 575.611
Remaining capacity: 1.65    Used capacity: 11.95    Costs: 374.766
17  17  17  17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 1.6 Used capacity: 12   Costs: 374.766
17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0   Used capacity: 13.6 Costs: 1215.51
8
    Base costs: 170
    Costs from 8 to the final destination: 884.658
Remaining capacity: 2.73    Used capacity: 10.87    Costs: 1812.5
18  2   5   11  11  16  16  16
    Base costs: 170
    Costs from 18 to the final destination: 865.8
    Costs from 2 to 18: 109.428
    Costs from 5 to 2: 3.476
    Costs from 11 to 5: 245.554
    Costs from 16 to 11: 165.553
Remaining capacity: 4.95    Used capacity: 8.65 Costs: 1402.17
3   3   3   3   3   3   1   8
    Base costs: 170
    Costs from 3 to the final destination: 150.78
    Costs from 1 to 3: 891.376
    Costs from 8 to 1: 0.451
Remaining capacity: 0.490001    Used capacity: 13.11    Costs: 568.103
7   7   7   7   7   20  20  20  20  4
    Base costs: 170
    Costs from 7 to the final destination: 18.997
    Costs from 20 to 7: 193.338
    Costs from 4 to 20: 124.521
Total costs of the solution: 8265.32
```

```
Remaining capacity: 5.7 Used capacity: 7.9  Costs: 619.181
23  23  4   4   4   4   20  20  20  20
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 4 to 23: 84.381
    Costs from 20 to 4: 123.644
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0   Used capacity: 13.6 Costs: 928.567
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0   Used capacity: 13.6 Costs: 738.665
6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 0   Used capacity: 13.6 Costs: 950.313
14
    Base costs: 170
    Costs from 14 to the final destination: 660.265
Remaining capacity: 0.44    Used capacity: 13.16    Costs: 1561.55
27  27  27  27  6   6   6   14
    Base costs: 170
    Costs from 27 to the final destination: 575.611
    Costs from 6 to 27: 320.643
    Costs from 14 to 6: 281.21
Remaining capacity: 6.95    Used capacity: 6.65 Costs: 391.602
3   3   17  17  17
    Base costs: 170
    Costs from 3 to the final destination: 150.78
    Costs from 17 to 3: 36.729
Remaining capacity: 3.39    Used capacity: 10.21    Costs: 1709.83
1   2   5   5   5   5   5   5   5   21  11  11
    Base costs: 170
    Costs from 1 to the final destination: 884.515
    Costs from 2 to 1: 151.373
    Costs from 5 to 2: 3.476
    Costs from 21 to 5: 214.809
    Costs from 11 to 21: 48.763
Total costs of the solution: 8756.85
```

```
Remaining capacity: 1.83    Used capacity: 11.77    Costs: 1354.15
23  23  4   4   27  27  27  18  18
    Base costs: 170
    Costs from 23 to the final destination: 172.051
    Costs from 4 to 23: 84.381
    Costs from 27 to 4: 599.856
    Costs from 18 to 27: 327.859
Remaining capacity: 0   Used capacity: 13.6 Costs: 811.864
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 0   Used capacity: 13.6 Costs: 811.864
28
    Base costs: 170
    Costs from 28 to the final destination: 641.864
Remaining capacity: 5.6 Used capacity: 8    Costs: 651.178
6
    Base costs: 170
    Costs from 6 to the final destination: 481.178
Remaining capacity: 0.6 Used capacity: 13   Costs: 343.263
17  17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0   Used capacity: 13.6 Costs: 343.263
17
    Base costs: 170
    Costs from 17 to the final destination: 173.263
Remaining capacity: 0.639999    Used capacity: 12.96    Costs: 357.509
3   3   3   3   17
    Base costs: 170
    Costs from 3 to the final destination: 150.78
    Costs from 17 to 3: 36.729
Remaining capacity: 2.32    Used capacity: 11.28    Costs: 1578.24
1   8   8   8   8   8   11  16
    Base costs: 170
    Costs from 1 to the final destination: 884.515
    Costs from 8 to 1: 0.451
    Costs from 11 to 8: 357.723
    Costs from 16 to 11: 165.553
Total costs of the solution: 6251.33
```

9.2 Abstract English

Vendor Managed Inventory is a concept to optimize supply chains by switching inventory responsibility from the manufacturing company to the supplier. This master's thesis is an implementation approach for the rail industry based on a practical example of Siemens Mobility Urban Transport plant Vienna. In the first part the optimal minimum and maximum inventory levels are calculated with the theory of the Newsvendor Model and the Order-Up-To-Model. Regarding the special environment of the project business of the rail industry and the limited warehouse capacity at plant Vienna, material availability must be satisfied but in the contrary capital commitment costs must be reduced. The second part focuses on transportation costs, emerging from the Vendor Managed Inventory suppliers. A Siemens specific Saving Algorithm with Direct Shipping and Milk-Runs is adapted from the Clarke and Wrights Saving Algorithm, to combine Vendor Managed Inventory Deliveries and reduce transportation costs.

9.3 Abstract German

Das Konzept von Vendor Managed Inventory beinhaltet die Optimierung von Lieferketten, indem die Verantwortung der Lagerbestände beim produzierenden Unternehmen auf die Lieferanten übertragen wird. Diese Masterarbeit ist ein Anwendungsversuch in der Schienenfahrzeugindustrie am Beispiel der Siemens Mobility Geschäftseinheit Urban Transport mit Werk in Wien. Der erste Teil bestimmt mit Hilfe des Newsvendor Models und des Order-Up-To Inventory Models die optimalen Mindest- und Maximallagerbestände. Unter Berücksichtigung des projektabhängigen Geschäftsmodells und der begrenzten Lagerfläche im Werk Wien, sollen durch die Umsetzung Materialverfügbarkeit erhöht werden sowie die Kapitalbindungskosten reduziert werden. Im zweiten Teil wird ein Siemens eigener Saving Algorithmus nach dem Clarke und Wright Saving Algorithmus entwickelt, basierend auf Direct Shipping und Milk-Runs. Lieferungen der Vendor Managed Inventory Lieferanten sollen hierbei kombiniert und Transportkosten reduziert werden.