Reducing Inventory and Order Delivery Time in an Internal Extended Value Chain

by

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B.S. Mechanical Engineering, United States Military Academy, 1993

Submitted to the Sloan School of Management and the Department of Materials Science Engineering in partial fulfillment of the requirements for the degrees of

Master of Business Administration
and
Master of Science in Materials Science Engineering

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2005

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Abstract
The extended value stream for the ABB Power Technologies Medium Voltage Business Area consists of numerous factories situated across various different countries. Most of these facilities were originally acquired by ABB to provide an established presence in local markets. In an effort to consolidate and align the Business Area's materials resources and reduce internal competition between similar factories, PTMV assigned specific products to specific factories on a regional basis. As a result, factories that use to have broad control of their entire manufacturing process from raw material to finished products are now either internal suppliers or internal customers of other ABB factories. The Business Area must now develop internal processes across these factories that focus on achieving timely delivery balanced with low inventory. In order to do so, it is essential for the Business Area to inspire individual factories with different cultures and languages to cooperate and work for a common goal.

This thesis describes how Value Stream Mapping can be used to analyze current order processes in individual factories and across multiple factories in a single value chain. Value Stream Mapping reveals the areas where non-value added time is the greatest in the overall order delivery process. Using this information, recommendations are formulated to reduce materials work-in-progress (WIP), and subsequently, system lead-time. This internship looked at the inventory management control of key components between two factories in the internal value chain. The impact of inventory cost due to inventory location, transportation, and production decisions is investigated and documented. Additionally, this thesis studies the strategic, cultural, and political challenges that ABB faces as it attempts to implement operational change management in a new organizational structure.

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ACKNOWLEDGEMENTS

Foremost, I would like to thank the Leaders for Manufacturing Program for giving me the opportunity to both learn and practice operations management during my two years at LFM. The program has been an exceptional experience and I leave a better and more knowledgeable person because of the time spent with classmates, faculty, and staff. I would also like express my gratitude to the Sloan School of Business and the Department of Materials Science and Engineering as well as my thesis advisors, Debbie Nightingale and Thomas Roemer.

I particularly want to thank those in ABB that made my internship experience possible. I am very grateful for the support given to me by the CRC and my project supervisor, Jukka Konttas, and for all those in Dalmine that made my stay in Italy enjoyable and memorable.

Lastly, I would like to thank my family and friends who have assisted me throughout my time at LFM and are a large part of any success that I have had or will have in the future. I truly appreciate the support from my parents, sisters, and most of all Kelly, who all have been part of making this experience possible.

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CHAPTER 1: COMPANY AND PROJECT INTRODUCTION

The information and analysis contained in this thesis is the result of a six month internship at Asea, Brown, and Boveri (ABB) Limited through the Leaders for Manufacturing (LFM) program at Massachusetts Institute of Technology (MIT). This internship was sponsored by the Corporate Research Center (CRC) in Vaasa, Finland and took place at the ABB Sace factory in Dalmine, Italy (ITSCB) and included visits to the ABB Calor factory in Ratingen, Germany (DECMS) and the ABB switchgear factory in Brno, Czech Republic (CZEJF). This project is based on a co-initiative between the Power Technologies Medium Voltage (PTMV) business area and the CRC that seeks to reduce order lead-times and reduce inventories across the PTMV internal extended value stream.

1.1 ABB Limited Company Background

ABB Limited is the result of a 1987 merger between the Swedish electrical engineering company, Asea, and the Swiss engineering company, Brown Boveri. This merger created the largest company in Europe in its industry with 180,000 employees. Soon after the merger, ABB made several acquisitions such as Westinghouse's power distribution and transmission business, AEG's steam turbine business, and Combustion Engineering to strengthen its position globally in the power industry. The company organized several small operating factories (roughly 200 employees each) through a matrix organization that focused on Business Areas (BAs) and country managers. BAs determined the global strategy and coordination of all factories in a particular business and related BAs were organized into Business Segments. In addition to reporting to BA managers, factory managers also reported to country managers that were responsible for profit-and-loss for ABB activities in each country.

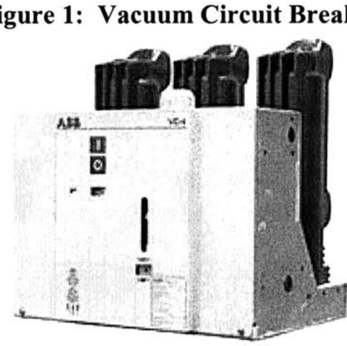
In the late 1990's, a changing business environment and the strains of geographic expansion (then 160,000 employees in over 100 countries) forced ABB to rethink its matrix organization. In 2001, ABB changed to a Front/Back organizational design in which the back end was to coordinate technology development in both automation and power, and the front end to focus on creating value to customers through four industry related segments responsible for sales and service. Under this new structure, BAs gained more responsibility and country managers lost power as the company focused more on product. Difficulties in transitioning to the new organizational design and a deteriorating global economic environment forced ABB in 2002 to quickly scrap the Front/Back structure and split the company into two main divisions, Power Technologies and Automation Technologies, along with a smaller stand alone unit, /the/ Oil, Gas, and Petrochemicals division. The Business Areas still operate with the divisions with focus on product families.[1]

1.2 Factory and Product Background

The internship project was based at a facility in the PTMV BA in Dalmine, Italy. The ABB Sace factory was an independent Italian factory before its purchase by ABB and consists of both the apparatus and switchgear production facilities. The plant has on average 200 employees across the two separate facilities and is both an internal supplier and customer in the PTMV extended value chain.

The apparatus factory produces medium voltage circuit breakers and vacuum contactors. This plant has three main product lines for its circuit breakers. Two of the lines consist of primary SF6 gas circuit breakers and primary vacuum embedded pole circuit breakers (see Figure 1), with a third product line consisting of a combination of both secondary SF6 and vacuum circuit breakers. All circuit breakers are used for industrial and commercial use to provide safety in the 12 to 24kV electrical range.

Figure 1: Vacuum Circuit Breaker



[1] D. Eleanor Westney, "ABB: From Icon to Crisis", (MIT Sloan School of Management)

The other facility located at ABB Sace is a Switchgear factory consisting of two main product lines. Of these two lines, the older UniSafe product is currently being phased out of production and is being replaced by the second product, the newer UniGear switchgear assembly (see Figure 2). Switchgear products are used commercially to receive incoming power and distribute it to buildings, ships, and industries so that can be used in various electrical applications.

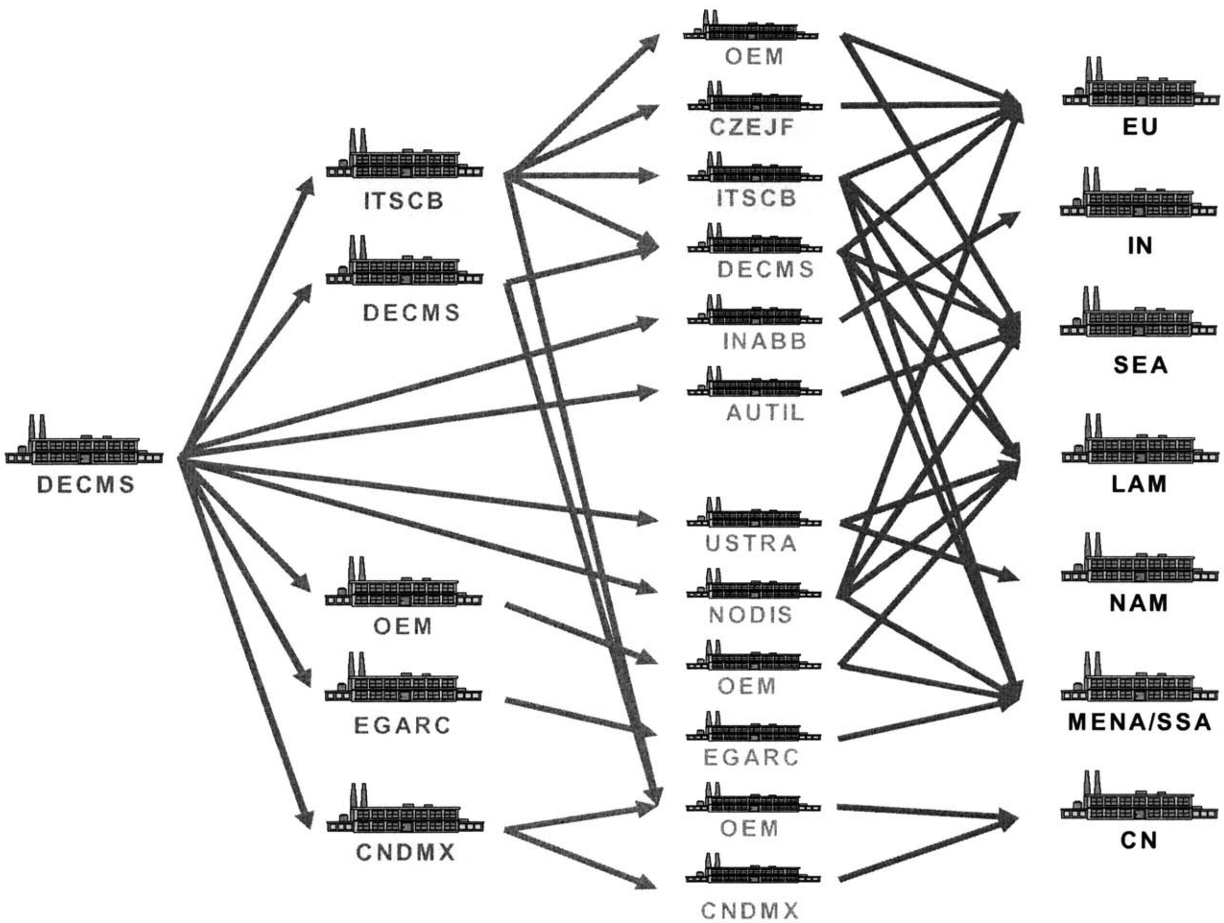
Figure 2: ABB UniGear Switchgear

ABB Sace provides an interesting perspective into the PTMV internal value chain because it is part of two links of the chain at a single location. ABB Sace Apparatus is a major supplier of circuit breakers and vacuum contactors to ABB Sace Switchgear. ABB Sace Switchgear is both a supplier directly to dealers and customers depending on the sales strategy and capability for different regions.

1.3 Project Motivation and Scope

The goal of this project was to support the CRC Vaasa initiative that seeks to reduce order and production lead-time, as well as inventory, across the PTVM internal value stream. The internal extended value stream for the PTMV vacuum technology products currently extends across three types of factories. The farthest upstream factory produces vacuum embedded poles and supplies a second stage factory producing circuit breakers, which subsequently supplies the final stage switchgear factory as shown in Figure 3:

Figure 3: PTMV Internal Extended Value Stream



The first two letters of the factory acronyms in this figure reflect the factory's country location and the following three letters are usually associated with the historical name of the factory. Currently the order, production, and transportation lead-times in this value chain are excessively long and inventory levels are very high. ABB switchgear factories are being challenged by non-integrated competitors that have shorter lead-times through local suppliers. This project focuses on reducing value chain inventory levels and overall throughput time in order to make ABB more responsive at lower cost. Specifically, the project focuses on three factories located in Ratingen, Germany, Dalmine, Italy, and Brno, Czech Republic. The factory in Ratingen, Germany (DECMS) supplies the key component of vacuum circuit breakers, vacuum embedded poles, to ABB circuit breaker factories. The circuit breaker factory in Dalmine (ITSCB) sends its products to various internal ABB switchgear factories including the factory in Dalmine. ABB

Sace Apparatus is also a supplier directly to distributors, original equipment manufacturers (OEMs), and other customers. As the last link in the internal ABB chain, the switchgear factories in Dalmine (ITSCB) and Brno, Czech Republic (CZEJF) provide the final product assembly before delivery to the end customer. Potential cost and throughput time reductions were explored during a six-month internship at the circuit breaker production facility located in Dalmine, Italy.

1.4 Thesis Overview

This thesis documents observations and lessons learned during the six-month internship to provide analysis and recommendations regarding operations for the PTMV value stream. The thesis first looks at order and production processes at the individual factories located in Dalmine, and then examines how key components arrive from internal upstream factories as well as how Dalmine delivers their products to downstream internal customers. Following this analysis is a global view of operations across the Business Area as a whole with respect to vacuum technologies and what operational challenges are inherent with the current strategic organizational structure. Lastly, the thesis discusses cultural and political aspects of the company that should be addressed in order to facilitate change management with the organization. The thesis is structured as follows:

Chapter 2 covers the project's value stream analysis. One of the main goals of the internship was to provide value stream maps of the both the switchgear and apparatus factories located in Dalmine, Italy in order to determine where inventory was waiting in the system and to see what processes consumed the most time. Another purpose for developing value stream maps was to show how the supply of vacuum embedded poles are ordered and received by the factory in Dalmine and how circuit breakers are delivered to internal down stream customers such as CZEJF. This analysis focuses on inefficient processes, WIP build-up, and order lead-time reduction.

Chapter 3 explains the Inventory Analysis performed during the internship with the goal of decreasing inventory and delivery times between internal factories. An emphasis of the project was the method of inventory placement and delivery of embedded vacuum poles between the factory sites located in Dalmine, Italy and Ratingen, Germany. An explanation of the current practice and an analysis using a periodic review inventory model is given.

Chapter 4 reviews the current order and delivery processes of circuit breakers between ABB factories in Dalmine, Italy and Brno, Czech Republic. Observations and suggestions concerning inventory levels and delivery times are provided with the goal of reducing both.

Chapter 5 examines the entire internal extended value stream across three levels of factories. Following the examination of operations in and around the factories located in Dalmine, the thesis inspects processes for the higher level organization and makes recommendations for reducing the level of inventories and the order lead-time throughout the system. Suggested solutions will include a future state value stream map and will discuss the "bull whip" effect common in vertical chains and method to mitigate this effect.

Chapter 6 develops the challenges of implementation of these recommendations through a strategic operational and organizational analysis of the Business Area. The chapter examines the current strategic organizational structure and discusses how the methods applied in this project support the risks associated with the structure.

Chapter 7 provides overall conclusions from the internship experience and supplies recommendations for achieving operational success and sustainability.

CHAPTER 2: VALUE STREAM MAPPING IN INDIVIDUAL FACTORIES

2.1 Introduction

The CRC is utilizing the process of value stream mapping in order to recognize process areas that provide opportunity for value creation and waste removal. Two types of value stream mapping are used in this project. Initially, the apparatus and switchgear factories in Dalmine are mapped as single factory entities delivering their product to their respective customer. Later, these individual factory maps can be incorporated with existing upstream factory maps to provide an extended value stream map between factories across vacuum embedded pole, circuit breaker, and switchgear production.

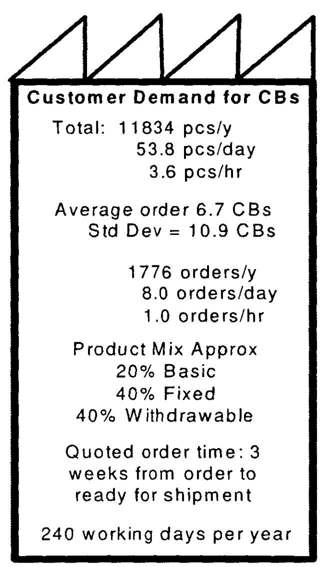
2.2 Value Stream Mapping Theory

The process of value stream mapping is an important step for companies attempting to make a "lean transformation". In the text, Lean Thinking, Jim Womack and Dan Jones separate this transformation into five steps of which value stream mapping is the fourth and most critical step. Highlighting the importance of this step, Mike Rother and John Shook provide additional guidance for value stream map creation in the text, Learning to See and Seeing the Whole. The first text focuses on mapping the order and delivery process through a single factory and the second text expands this focus to other factories both upstream and downstream until the product reaches the end customer.

The value stream mapping process observes and records both material and informational flows in order to document and display every action taken from the moment a factory receives an order until the customer receives the product. A single map focuses on a specific product in the factory and attempts to capture the flow or flows related to its production. Rother and Shook recommend that a single Value Stream Manager be responsible and highly involved in creating the map to develop an understanding of the overall order and delivery process instead of focusing on individual flows. According to the text, it is best if the manager starts mapping from the shipping point and works upstream toward the order receiving point. Information at each point along the line is developed from both individual observation and interviewing knowledgeable workers. Initially, manager can use this information to create a current-state map that reflects how processes are currently established. After the creation of the current-state map, managers should work with all those involved with the many processes to redesign how orders are fulfilled to the customer. In doing so, the Value Stream Manager can create a future-state map the gives the company a goal to work towards.

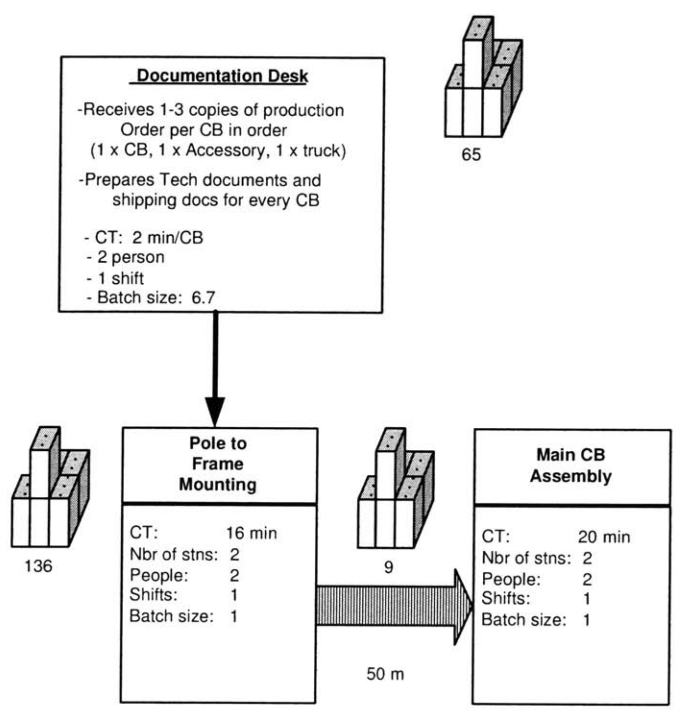
When creating a current-state map, the first item that should be studied is the customer because the customer's needs are what should shape any order fulfillment process development. Finding the customer's average periodic demand for a product helps show what the order incoming rate is on a daily and hourly basis. Determining the average order size and the standard deviation of both order size and customer demand can also be useful in gaining an understanding of the customer order pattern. The customer information should be positioned at the right hand side of the process flow in a data box as reflected in Figure 4:

Figure 4: Value Stream Map Customer Information Data Box



After gathering the customer data, every process step involved between the reception of an order and the arrival of the product at the customer site should be studied and recorded. Starting from the process directly upstream from the customer, the stage cycle time, number of stations, number of operators, working time, batch size, changeover time, uptime, and possibly a brief description of the work performed is gathered and used to create a process stage box. Once all the process stages have been identified, they can be linked by a either a broad checkered line if pushed material flow or a narrow line if information flow. In the case of electronic information flows, the narrow line should have a lightening-like bend. All lines should have an arrow in order to denote the direction of process flow and the distance between stages if materials or information are physically transported. Next, the inventory that has accumulated between process stages should be counted and documented on the value stream map before each process box. An example of these combined steps is shown in Figure 5:

Figure 5: Value Stream Map Process Box



Information processes usually flow from right to left at the top of the map as the order is received from the customer, and production processes proceed from left to right until the product is delivered to the customer. Deliveries are denoted by a broad arrow.

Lastly, the customer order's timeline is determined by showing the time at each station that is spent creating the product for which the customer is willing to pay that is referred to as the value added time. Ideally this time would be the cycle time, but this is often not the case due to operational waste at a process stage. The lead-time through the process is determined next by taking the inventory count waiting for the process stage and dividing it by the incoming customer order rate. These times are recorded below each process stage and are added across all stages to give the total valued added time and the actual total lead-time of the order process. By dividing the total value added time by the actual total lead-time, the percent of time dedicated to value added process can be determined. Examples of individual factory maps can be referenced in Appendices B and C.[2]

2.3 Factory Mapping at ABB Sace Apparatus

One of the CRC's primary goals for this project was to develop a value stream map of ABB Sace's Apparatus Value Stream and, if possible, also for the Sace Switchgear factory. At the time of the internship, circuit breaker lead-time at Sace was three to four weeks plus transportation time. A similar ABB factory operating in China had an order lead-time of roughly one and a half weeks while a sister factory in Germany had a time of up to three weeks with one week supplier time allocated for parts being order specific. One of the main differences between the Sace factory and the apparatus factory in Xiamen, China, is that the Sace factory has much greater product variation.

Implementing the techniques provided in Learning to See, interviews were conducted and all processes involved in the delivery of the vacuum circuit breaker product were mapped. A completed map of Sace's vacuum circuit breaker is provided in Appendix B. At the time of the

[2] Mike Rother and John Shook, Learning to See, (The Lean Enterprise Institute, Brookline, MA, June 2003) 3-37.

map creation, the factory was averaging a demand rate of 53.8 circuit breakers per day. The average daily order size was 6.7 breakers with a standard deviation of 10.9 breakers per order, giving an average demand of 8 orders per day. Toward the end of the internship, the daily demand began to increase and was expected to continue to increase to more than 70/day. Production of circuit breakers is performed on a made-to-order basis and neither Sace nor its downstream customers hold an inventory of completed circuit breakers. From the mapping, the circuit breaker order delivery process seemed to highlight three main phases where inventory pooled on a weekly basis and roughly corresponded to the three weeks lead-time quoted by ABB Dalmine to its customers.

2.3.1 The First Phase: Production Scheduling

The ABB Sace Apparatus factory operates on a weekly planning schedule and the accumulation of WIP in the value stream map reflects the movement of orders and materials related to this scheduling. Based on a five-day work week that starts on Monday, the factory schedules weekly circuit breaker production during the day on Monday. Orders that are received in the time period between Monday afternoon and Friday sit in the planning queue until the following week's planning meeting. Based on the average rate of incoming orders and an average waiting time of 2.5 working days, the expected WIP count in the queue for Monday's production plan should be roughly twenty orders, or 134 breakers. However, the actual count is 48 orders consisting of roughly 321 breakers, which is six working days worth of demand that is waiting for production scheduling. The count in the actual map was taken near the end of the week, which could account for some of the excess orders, but many of these orders had been received in advance of the three to four week lead-time requirements. Some of these orders were due to calculated long-range planning by customers. However, many were due to ABB internal agreements between factories that pushed for earlier circuit breaker ordering which will be discussed in further detail in Chapter 3.

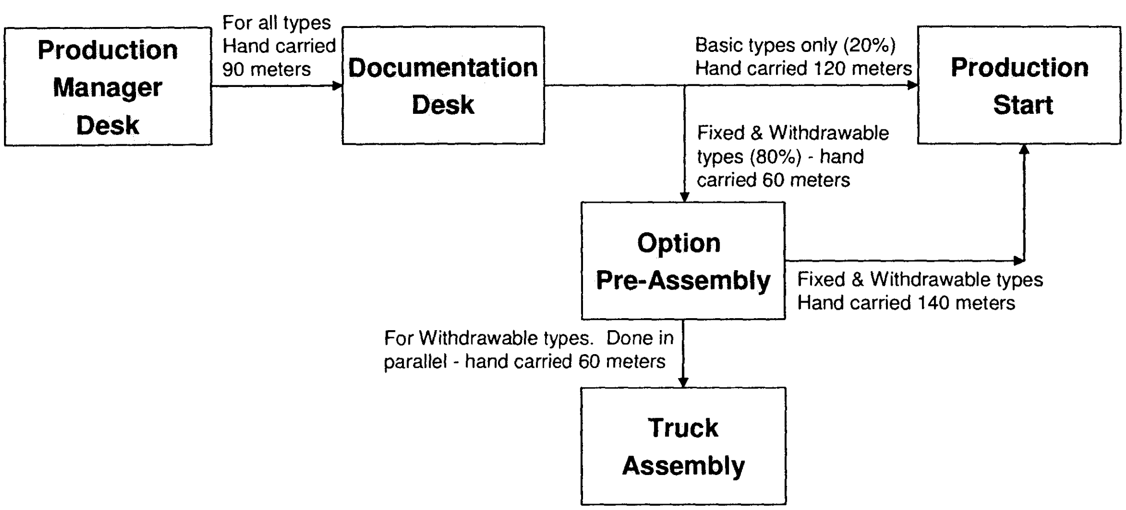
2.3.2 The Second Phase: Product Launch

After the Monday planning meeting, the orders go through the launch process in batches. Each week's launch is performed Monday through Thursday for orders that must be produced for the following week's shipment. Unlike the production planning phase of the order process, both the production launch and circuit breaker production processes are dependent on which general type of breaker the order calls for. The production line is modified to accommodate the flow of each one of three types of circuit breaker: basic, fixed, or withdrawable. A brief explanation of these three types is necessary in order to understand the different production requirements and subsequent production line modifications.

Basic circuit breakers, as the name implies, require no customization because the customer has not selected any additional options. These breakers are usually sold to customers in foreign markets with basic requirements or to customers who wish to customize the product themselves. Fixed circuit breakers require the sub-assembly, kitting, assembly, and test of circuit breaker options provided by ABB to the customer. The sub-assembly and kitting of these options takes place off the main production line. The withdrawable circuit breaker is similar to the fixed with the exception of a carriage, or "truck", assembly that is a safety feature. Medium voltage withdrawable circuit breakers are generally installed in switchgear cabinets, and the carriage allows them to be easily pulled out of the cabinet when they require maintenance or repair. The carriages consist of many types and are made to order at a sub-assembly station located off the main vacuum circuit breaker production line. The current product mix for Sace is approximately 20% basic, 40% fixed, and 40% withdrawable circuit breakers. This product mix affects the launch process significantly due to the fact that the current launch process flows through the sub-assembly areas for both circuit breaker options and carriages. Throughout the week, all orders are printed and hand-carried by the product manager between each of three separate launch stages.

The first stage for all three circuit breaker order types is the documentation desk where operating manuals are attached to the orders for all types. Within this stage, additional instructions for sub-assembly and the assembly of options and carriages for fixed and withdrawable circuit breaker orders are also printed. From this point, basic circuit breaker orders are carried directly to the production start point. Fixed and withdrawable circuit breaker orders are picked up by the production manager and taken to the options sub-assembly point. If withdrawable, a copy of the production order is also carried to the carriage sub-assembly area. Due to complications with inventory level tracking, launch of fixed and withdrawable orders are held at the options sub-assembly station until every customer option can be assembled for the entire order to ensure material availability. After clearing this final hurdle, orders are transported by the production manager to the production start point. This launch process occurs throughout the week in random batches of circuit breaker orders during which the production manager tries to launch large orders with regard to delivery date of order, size of order, and product type of order. A map of the production launch process in displayed in Figure 6:

Figure 6: Circuit Breaker Production Launch Process



The value stream map accurately reflects the launch process as WIP is seen to reside in all three stages of the launch process: the documentation stage (65 circuit breakers), the sub-assembly stage (37 breakers), and the production start stage (138 breakers). These three stages combine for a total of 4.4 working days of demand. As mentioned previously, these WIP counts are taken toward the end of the week when a majority of the launch orders are nearing production. Earlier WIP counts during different stages of the week show most of the launch WIP in the documentation area early in the week, then at the sub-assembly area during the middle of the week, as is expected from the current launch process.

2.3.3 The Third Phase: Production and Delivery

Circuit breaker production is typically planned to occur between the Thursdays of the second and third weeks of order processing. Some types of breakers are allowed an extra week in this planning phase based on increased manufacture time or component type. At the beginning of the production phase, all breakers move through the first three stations regardless of whether basic, fixed or withdrawable. After this point, the basic breakers are sent to the finishing stage, then the final two test stages, before being prepped for packaging and shipping. The fixed and withdrawable breakers are directed toward two concurrent stations that assemble and test customer options. Fixed breakers then follow the finishing process undertaken by the basic breakers, while withdrawable breakers process through three additional stations before following the finishing path.

The value stream map of the production process shows a WIP total of 46 breakers, or less than one day's demand, in processes leading up to the packing stage. Averages across all these stages during different times of the week were between 40 and 80 with an average of 63, or slightly more than the daily average demand. From the map, one can see that 99 pieces, nearly two days' worth of demand, existed as finished goods inventory (FGI) awaiting crating and transportation to the a contracted finished goods warehouse. Weekly averages of product undergoing crating and staging for warehouse delivery averaged nearly 134 pieces throughout different times of the week and day.

The last WIP value in the Apparatus Value Stream Map demonstrates the FGI that sits in the contracted warehouse pending shipment to the customer site. This FGI is estimated to be 175 breakers, or over three days' demand of product. This value was estimated from a total of breakers awaiting shipment in two separate shipping warehouses that Sace uses for its distribution. Circuit breaker numbers in these warehouses are tracked variously on a bi-weekly or monthly basis. The count utilized in this map is from one of the tracking reports with the knowledge of product order mix. Shipment schedules to customers vary depending on customer location. Most shipping occurs two times per week, with occasionally reduced frequency.

2.3.4 Final Results

The mapping of circuit breaker order processes reveals through the WIP count that across the three order types, the order lead-time for one breaker is between 15.5 and 16.3 days, shipping withstanding. From the interviewing process, actual process times for each stage were determined and included in the map. This information is used to establish the actual value-added time required before a circuit breaker ships to the customer, which can be compared to the actual time. The results of the value stream mapping are shown in Figure 7:

Figure 7: Apparatus Value Stream Results

Basic	Production Lead Time	Order Lead Time
	5.0 d/CB	15.5 d/ord
	2.1 h/CB	5.0 h/ord
	Production Value Add Time	Total Value Add Time

Fixed	Production Lead Time	Order Lead Time
	5.1 d/CB	16.2 d/ord
	2.6 h/CB	6.8 h/ord
	Production Value Add Time	Total Value Add Time

Withdrawable	Production Lead Time	Order Lead Time
	5.2 d/CB	16.3 d/ord
	3.1 h/CB	7.3 h/ord
	Production Value Add Time	Total Value Add Time

Between basic and withdrawable versions, the value added order lead-time was determined to be between 5.0 and 7.3 hours for one breaker. When focusing only on production times only, the actual time of a circuit breaker ranged from 5.0 to 5.2 days for the three types of product while the value added process time breaks down to 2.1 hours per breaker for basic, 2.6 for fixed, and 3.1 for withdrawable. The percentage of value added time was determined using 15 hours for production time to reflect the two operating shifts and 8 hours for all other operations performed off the production line. For basic the percentage of value added time is 3.14%, for fixed the percentage is 4.11%, and for withdrawable the figure is 4.38%.

2.3.5 Potential Lead-time Reduction

Currently, most new circuit breaker orders average at least a half-week waiting to go into the weekly production planning meeting before they can be scheduled for launch. When reviewing planning processes in similar ABB circuit breaker manufacturing factories, production planning is done on a daily basis and long-term planning is done one to two times per week. After a new order is received in the comparable similar ABB factories, a material check is run the same evening, it's material availability is matched with production capacity, and the customer delivery date is slotted for production. At this time, these factories can give their customers feedback on the expected delivery date. Moving from a weekly production meeting to a daily meeting is an integral step in making the overall order delivery process more continuous. The weekly batch process impedes the fluidity of production launch and production downstream.

Production launch is currently conducted in many sub-batches of orders that comprise a three to four day larger batch. The actual production launch consists of steps that should take only minutes, however, the current process takes days. Some potential enhancements to this process are creating better physical proximity by moving process steps closer together, and better coordination of the option and sub-assembly stations. For fixed orders with options, the production manager must walk at a minimum of 270m during the launch process between all steps. If the circuit breaker is withdrawable, he must walk even further. Operations at the documentation desk should be co-located with the production manager cell so that each order could immediately flow from launch initiation to documentation.

After documentation, the order should go straight to the first production site if streamlined coordination existed between the main line and the sub-assembly and carriage lines. Actually, the line at ABB Sace was set up with this type of coordination in mind. However, material parts shortages in the sub-assembly area have led to production stoppages on the production line; when orders reach the options assembly they have no completed sub-assemblies. This has led to the absolute completion of sub-assemblies before orders are launched. Jointly, even if parts are available, timing of order and sub-assembly production is difficult. Current efforts are underway to develop better material management in the sub-assembly area, but growth in the number of product options make holding inventory in this area more and more expensive. Once the material shortage issue is solved, substantial effort should be applied to coordinate the production of sub-assemblies and the basic circuit breaker so that they meet later in the line. This can potentially save over thirty-five minutes per order of production time.

The WIP along the breaker production line is not significantly high compared to the WIP of other processes. However, WIP reduction is possible with the implementation of a control process such as ConWIP. Based on a production line simulation performed using the software package, Simul8 (see Appendix E), and by observing the line over time, the bottleneck operation was determined to be the circuit breaker speed test.

This test occurs at the end of the basic breaker line before production is divided between the three major types. Situating the control point or the low voltage test point at the end of the line should result in reduced WIP. This will allow newly launched products to travel faster through the production process.

Much of the inventory build-up in the system occurs after the completion of circuit breaker production. FGI is picked up from the factory once per day and moved to one of two FGI warehouses to await transportation. Circuit breaker orders are shipped from the warehouse to the customer once or twice per week. The same company that is contracted for the warehouse is also responsible for many of the customer shipments. To this point, most delivery decisions have been based on the costs of transportation and inventory holding, with little regard for costs of unmoved inventory or the inventory's cost of capital. Chapters 3 and 4 will address delivery options and their impact on overall cost to ABB.

2.4 Mapping Across the Switchgear Factory

As mentioned in Chapter 1, switchgear allows customers to receive power from outside sources in order to convert and distribute the power to where the buyer needs it. The circuit breakers produced at the Apparatus factory in Sace are one of many important components that are used in the switchgear product, as well as in current and voltage transformers and power protection relays. Figure 1 shows that the circuit breaker factory in Sace serves many internal ABB switchgear factories as well as OEM customers. The project looked primarily at two switchgear factories being served by Sace's apparatus factory, the one co-located in Dalmine and another in Brno, Czech Republic, which is Sace Apparatus' largest customer.

Because the internship took place in Dalmine, providing an additional value stream map of the customer order process for a switchgear plant became necessary in order to map the order process across the three factory stages of PTMV order fulfillment. As with the value stream mapping performed in the Sace Apparatus factory, interviews and order WIP counts were performed in the Sace Switchgear factory along the UniGear product line with respect to those UniGear orders that called for vacuum type circuit breakers. Although most of the production process times and WIP were easily determined, upstream order process times related to engineering and production planning were more difficult to understand due to unforeseen, but necessary, organizational events that occurred during the time of the internship. Demand rates, process times, and WIP counts observed during this time period are not necessarily accurate, and thus, prevented the completion of a clear value stream map for the Sace Switchgear factory. However, comparing the map with the completed map of a similar factory in Xiamen, China, and comparing it to operations in its sister factory in Brno still allowed for more general observations from the mapping process.

2.4.1 Locations of Inventory Build-Up

A generalized map of the order delivery process for the Sace Switchgear factory can be viewed in Appendix C. One of the main points to take away from this picture is that a major source of WIP in the order process occurs before the engineering phase. The UniGear product is more complicated than the circuit breaker produced in the Apparatus plant. UniGear is much less standardized, having more options with a high percentage of orders demanding engineering customization. This customization requires engineers to determine part requirements and to develop drawings and wiring diagrams that meet customer order requirements. This accumulation of order WIP at engineering is not isolated to the plant located in Dalmine. The accumulation also occurs at the factories in China and Czech Republic, though to a smaller degree where Czech Republic's customers require less product customization.

When viewing the map, a second location of WIP accumulation surfaces before production launch. Much of this stockpiling is due to long component lead-times after the engineering group has specified the component requirement and released it to purchasing. The circuit breakers lead-times are 3-4 weeks, transformers from an ABB factory in the Czech Republic are 4-5 weeks, and protection relays from both ABB factories and outside vendors are anywhere from 4-7 weeks. The other factories in both China and Czech Republic also experience order WIP before production launch due to long component lead-times, but ABB Sace has an additional outsourced component requirement that the other two do not have. The Sace Switchgear factory outsources the assembly of its Low Voltage Compartment (LVC) due to the labor intensity involved and the higher labor costs of Italy compared to China and the Czech Republic. In Sace, they gather the electronic sub-components required for each order before sending them to the LVC assembler, while non-electronic material is sent directly to the outsourced company. The reason for this sub-component division is that it saves the smaller, outsourced assemblers from purchasing the expensive electronic sub-components, reducing their financial burden in inventory.

The last significant location of order delivery WIP occurs in the production phase of the UniGear product. The UniGear production line in both Dalmine and Brno consists of several production stages that perform basic assembly of individual cabinets before an individual low-voltage test is performed. After this test, all cabinets (roughly 11-13 on average) are wired together in an order for a final integrated test. An integrated customer test often follows, as necessary. Due to the nature of the testing, individual cabinets must essentially undergo the final integrated test in a batch size equal to the size of the order. These combined tests can take up to five hours per panel.

Due to the testing process, higher WIP counts are expected in the finishing stations. However, the factory in Dalmine had significantly higher WIP counts than Brno because Dalmine spent more time per order in the finishing area. A probable cause of this increased time is that LVCs and circuit breakers at both locations are sometimes installed at the finishing stage instead of the individual cabinet line as planned, requiring time for installation and some retest. Sace's percentage of LVCs and circuit breakers installed in the finishing area are much higher than that of the factory in Brno (90% compared to 50%), presumably leading to longer finishing times and higher WIP counts. Other factors to consider are that Sace's products are more customized and can possibly require more time for cabinet integration and specific test requirements.

2.4.2 Potential Process Improvements

The engineering process is a bottleneck in every ABB switchgear factory due to the labor intensity involved in determining material specifications, and in the development of schematics and drawings. However, much of the time spent in ABB Sace also seemed to be related to waiting for specifications from the customer and for customer approval after each engineering step. Possible ways to reduce this wait time is to create a more technical sales team that can determine specifications at the time of the order.

Of course, the long lead-time of the switchgear production process itself may lead to the customer being uncertain of what requirements they may need at the time of order. This creates a reinforcing loop in which sub-component designs must wait for more information and after being ordered, the long sub-component lead-times push delivery dates out further. Hence, ABB's desire to reduce internal sub-component production and delivery times within the internal chain. Other actions that ABB can take to reduce wait time are to work on standardizing customer options, with an automated engineering material selection and drawing requirements options selection. Teleconferencing with customers during the engineering phase for customer changes or approval would reduce the delay of physical or electronic mail response back and forth.

From the production line standpoint, ABB Sace needs to reduce the number of cabinets in the final test area. In their current process, all cabinets in an order are wired together as they come off the production line and are connected with copper busbars for testing purposes. Similar factories have a mix of testing that ranges from individual cabinet final testing to order testing with inter-cabinet wiring only. ABB could consider an analysis of the cost of developing individual cabinet testing compared to the cost of WIP inventory in the final testing area. Reducing the requirement to individual cabinets would allow the line to convert to a full individual cabinet production flow unless customer testing is required. This would also significantly reduce the overall lead-time of the switchgear itself, which would reduce customer uncertainty at the time of order and limit the time for customers to make order changes.

ABB Switchgear in Dalmine must focus more on the coordination of the delivery of the LVC from outsourced suppliers and perhaps review the decision to outsource this critical component. Because specifications and material determination from engineering are late, parts for the LVC are not available to allow the LVC to be fed into the production line. Instead, the LVC is taken to the testing stage and inserted in this area. As this testing area is itself the production bottleneck, the delay in LVCs creates a serious WIP problem. Production planning currently tries to schedule production based on LVC completion and delivery dates from the outsourced vendor. But because of sub-assembly delays due to lack of material, panel production begins and pushes LVC installment to the end of the line. ABB Sace is trying to address this problem through design standardization and a reduction of components across different customer options. This should reduce production time at the supplier site and could reduce sub-component lead-times also.

Due to outsourcing, the LVC for Sace requires an additional two days of production time due to transportation of sub-component material to the outsourced vendor and shipping the completed LVC to the switchgear factory. ABB Sace currently procures the more expensive LVC sub-components and has them delivered to their factory. They have a department that gathers this material and manages its delivery to the outsourced vendor. ABB should consider ways to have this material sent directly to the outsourced vendor to reduce the redundant transportation time and to reduce the material management factor for the switchgear factory. The LVC component is a very labor-intensive assembly, and the decision to outsource the assembly was due to higher employment costs in the local country. If engineering, sub-component delivery, and supplier production times can be effectively reduced to allow the LVC to be installed on the production line, then the outsourcing decision seems valid with strong coordination. However, if LVC lead-times continue to be long and force continued installation in the product testing area, the impact of WIP inventory cost should be figured into the cost analysis if it has not already.

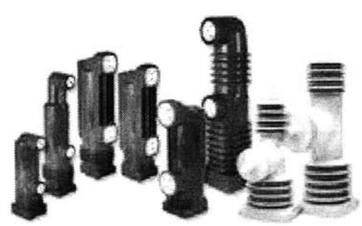
CHAPTER 3: ORDER FULFILLMENT AND INVENTORY MANAGEMENT BETWEEN DALMINE AND RATINGEN

3.1 Introduction

Historically in ABB, inventory management between individual factories resulted from negotiations between involved parties of each site. The agreements focused on each plant's strategy to minimize its own costs without considering the impact on other ABB factories, the product group, or ABB as a whole. ABB as a company, and the Business Areas specifically, have begun to develop inventory policies that provide the most benefit across the whole Business Area, as is the case in PTMV.

With regard to cost in the production of vacuum circuit breakers, the main components are the three vacuum embedded poles per breaker that amount to roughly 40% of the breaker's cost and are shown in Figure 8:

Figure 8: ABB Vacuum Embedded Poles



Referring back to Figure 1, it is evident that all vacuum embedded poles for ABB PTMV are produced at a single facility in Ratingen, Germany. The Sace Apparatus factory (ITSCB) is a major customer of DECMS as is the apparatus plant in China and, to a lesser extent, the circuit breaker plant in Poland. Therefore, management of the inventory between these two factories greatly impacts the company's ability to sustain high on-time delivery as well as the overall cost of inventory in the extended value chain. For this reason, inventory at this link of the chain is of key interest to the Business Area and was a focus of this project.

In addition to focusing on inventory management between the Sace Apparatus factory and its main internal supplier, the internship also focused on the inventory policy agreement between the Italian circuit breaker factory and its major internal customer, the CZEJF factory in Brno, Czech Republic. In contrast to vacuum embedded poles produced between DECMS and ITSCB that are made to replace inventory stock, circuit breakers between ITSCB and CZEJF are produced to fill specific customer orders. While primarily focusing on inventory management with both its main internal upstream and downstream suppliers, the internship also provided the opportunity to study all three factories and evaluate their current make-to-stock and make-to-order policies with regard to overall inventory strategy.

3.2 Current Processes Between ITSCB and DECMS

Currently, ITSCB orders ten types of vacuum embedded poles from the DECMS factory in Ratingen, Germany. Under the existing agreement between factories, DECMS supplies the Sace Apparatus facility based on a locked monthly forecast. The Sace plant provides the Ratingen site with its forecasted monthly demand for each type of pole a full month before the actual orders can be placed from Dalmine. This process gives DECMS a full month to plan their production in order to increase their stock levels to meet Sace's full demand at the beginning of each month. Production planning estimates their monthly forecast by applying a historical usage mix of pole type to the demand forecasts for total vacuum circuit breakers provided from their marketing department.

ABB Sace currently orders their embedded poles from DECMS on a weekly basis every Monday. ITSCB is able to vary their weekly order of poles, but at the final week of the month they are required to fulfill the order amount they had forecasted two months earlier. If the customer demand for Sace is greater than forecasted, they must either hope that DECMS has overstock of that specific pole or they must wait for DECMS to produce a rush order, which can take well over two weeks. The current lead-time of DECMS' production to customers not bound by forecast is four weeks.

Sace places their embedded pole order on every Monday via e-mail and DECMS receives the order and then sends the vacuum embedded poles as a partial shipment through a contracted carrier, usually on a Wednesday. The carrier makes an additional stop within Germany before departing for Dalmine, so shipments do not arrive in Dalmine until the following Monday or Tuesday. They are received through the materials handling department and made ready for the beginning of the circuit breaker production that usually begins on Thursday of the second week of the three-week order process.

DECMS stages the forecasted inventory for Sace that is accumulated the weeks before the first of each month, and continues to hold this amount until it is slowly depleted throughout the month. The plant in Dalmine holds their cycle stock plus a self-determined level of safety stock that is equal to roughly two weeks worth of forecasted demand. Additional inventory in the system exists as product in transit between the sites, which takes approximately one week to transport.

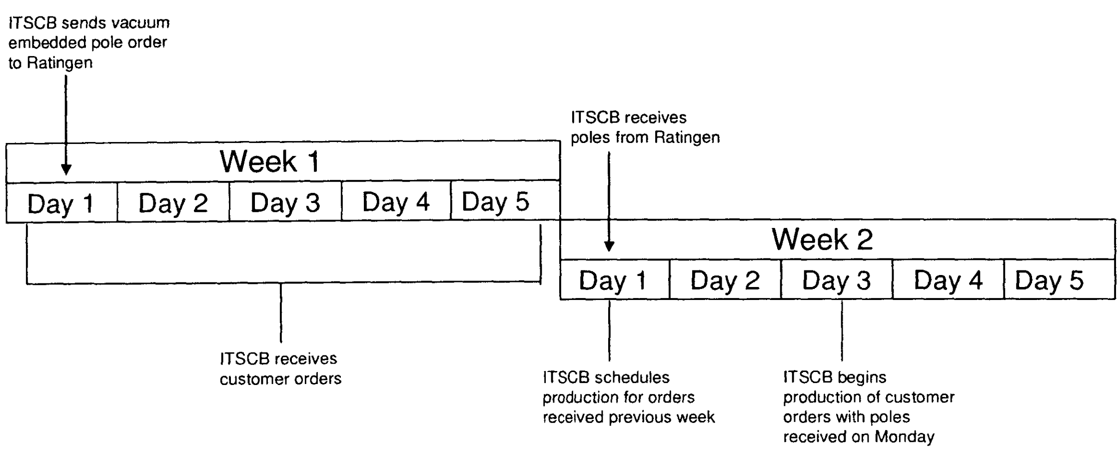
3.3 Sources of Excessive Inventory

The operations and production planning managers at ITSCB were greatly concerned about the order fulfillment agreement they shared with the vacuum embedded pole production facility in Ratingen. The current process had severe repercussions if they were either above or below their projected forecast. If they came in below their forecast, Sace was still obligated to purchase the remaining poles, which led to an increase in their current inventory. In the event that their demand was greater than their forecast, Sace had to hope their safety stock was sufficient to meet the surge. If safety stock was insufficient, Sace would miss their customer deliveries by anywhere from two to four weeks. Since many of Sace's customers were also ABB factories, such a delay could seriously impact the delivery of ABB Switchgear to customers downstream. The ITSCB's solution to this problem was most often to over-forecast, and their obligation to buy the excess stock at the end of the month resulted in consistently excessive inventories at Sace.

The fundamental problem for ITSCB was the inability to predict demand for their products, which had lead-times to the customer of four to five weeks including delivery. At the time they needed to provide the locked-in forecast to DECMS, they had few customer orders directly related to the provided estimate. As will be discussed later in this chapter, Sace, in their own manner, passed this forecast requirement further downstream to the switchgear factories. Sace would ask downstream customers to place circuit breaker orders as much as three weeks in advance, which resulted in inventory accumulation of circuit breakers at the factories.

Not only did ABB Sace have difficulty in forecasting monthly demand, they could not accurately project what they needed on a weekly basis. When ITSCB placed their pole orders every Monday, the quantity would be an estimate of the majority of customer orders to be received by ABB Sace during the rest of the week that would undergo production scheduling and launch the following week as shown if Figure 9:

Figure 9: Vacuum Embedded Pole Order Timeline



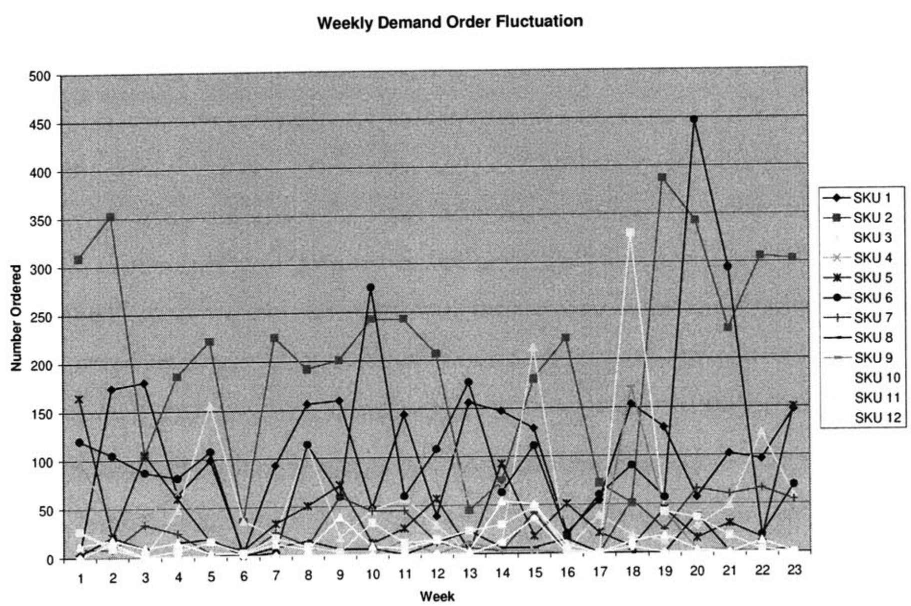
The greatest reason for ITSCB's inability to provide an accurate forecast in advance is the high variability of vacuum embedded pole demand. Table 1 demonstrates the demand variability for Sace's ten primary and two secondary pole types:

Table 1: ITSCB Vacuum Imbedded Pole Demand

Item *Vac Embedded Poles*	Description	Weekly demand (# poles)	Std Dev of weekly demand (# poles)
GCE7003979R0131	P1 VG4S 12-17,5kV	150	56.1
GCE7003979R0132	P1 VG4 12-17,5kV	302	102.9
GCE7003979R0133	P1 VG5 12-17,5kV	71	53.7
GCE7004730R0101	P4 VG5 24Kv	51	38.1
GCE7004730R0104	P4 VG4 24kV	68	44.5
GCE7004730R0105	P4 VG4S 24kV	161	103.6
GCE7005745R0152	P2 VG4S 12-17,5kV	41	23.9
GCE7005757R0123	P5 VG4S 24KV	13	9.8
GCE7007604R0101	P3-VG4	16	36.1
GCE7007604R0103	P3 VG4S	4	8.2
GCE7007609R0109	VD4/R P4-S VG5	33	69.9
GCE7007609R0104	VD4/R P4-S VG4	13	14.9

The demand variation is shown graphically in Figure 10:

Figure 10: Weekly Order Fluctuation by Pole Type



3.4 Overview of Inventory Management Model

Due to highly variable demand creating difficulty with accurate forecasting, PTMV and the CRC wanted to consider an inventory replenishment model. One method of inventory management is a stock replenishment model known as a periodic review policy. In this type of model, inventory levels are reviewed on a periodic basis and the amount of inventory used since the last review is reordered. When using this policy, the costs of placing orders are designated as fixed costs and do not factor into the determination of inventory levels. The appropriate levels are instead dependent on only the average demand during the periodic interval and the safety stock needed to protect against deviations from average demand.[3]

A similar inventory management system to the periodic review model is the continuous review model, in which inventory is reordered when inventories fall below a pre-determined level. This model requires constant monitoring of inventory levels and orders can be placed anytime during the normal business cycle. Continuous review models are very favorable for high value items that justify the expense of establishing a constant inventory monitoring system or if there are fixed order sizes dictated by the supplier. Periodic review models are more favorable for low volume and low cost items. They are also useful for items with joint dependency or for supplier mandated fixed reorder intervals.[4]

In the case for ABB Sace and Calor, the vacuum embedded poles are high cost and high volume items. Because they are also monitored by an SAP MRP system that could conceivably provide constant tracking of inventory levels, a continuous review policy at first seems like a good fit. However, the DECMS manufacturing process for vacuum embedded poles requires batch processing due to oven and molding steps. Currently, the production process is conducted from Monday through Saturday in large batches, and molds are cleaned and changed on a weekly basis during the remaining day of the week. They operate in this manner because of the long cleaning and changeover times, between eight and ten hours, for the molding required in the

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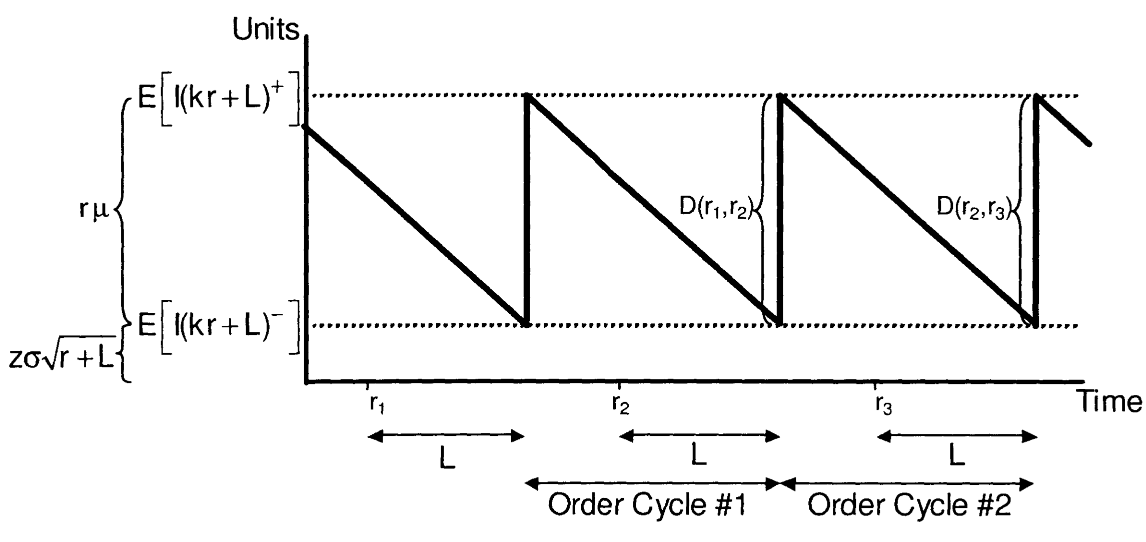
[3] David Simchi-Levy, Philip Kaminsky, and Edith Simchi-Levy, Designing and Managing the Supply Chain, (McGraw-Hill Irwin, 2003) 62-63.
[4] Sean P. Willems, "Inventory Notes", (Boston University, Copyright © 2001) This note is developed from lecture notes of Stephen C. Graves.

manufacturing process. Because their current manufacturing process is restricted to a weekly production cycle, the periodic review model seems to be the better approach for determining inventory.

Inventory held in the system consists to two types, cycle stock and safety stock. In the case of periodic review, the cycle stock is the expected inventory to be used in production during the course of the predetermined order period and the safety stock is inventory held to safeguard against variations to the required production quantity. The base stock quantity is the sum of cycle and safety stock which gives the expected maximum stock during the order period. During the period, inventory decreases as stock is pulled for production until the end of the period when inventory levels should theoretically fall to the safety stock level. At this point in time, new stock arrives from the supplier to replenish inventory levels back to the base stock level. Figure 11 reflects the expected behavior of inventory using a periodic review system.[5]

Figure 11: Expected Behavior of Period Review Inventory System



In this figure, r represents the period time and μ is the customer demand so that rμ is the demand for specified period. The equations used to determine the safety stock and the base stock inventory levels are:

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[5] Ibid

Equation 1: Safety Stock Equation

$$SS = z * \sigma * \sqrt{r + L}$$

where SS is the system safety stock, z is the safety factor which determines percent of service level, σ is the standard deviation of period demand, r is the time period between orders, and L is the delivery time of each order.

Equation 2: Base Stock Equation

$$BaseStock = r\mu + (z * \sigma * \sqrt{r + L})$$

It is also possible to take into account variability in the standard lead-time, whether due to supplier production variability or transportation volatility. Modifying the safety stock equation above to take these shifts into account yields an equation of:

Equation 3: Modified Safety Stock Equation

$$SS = z * \sqrt{(\mu^2 * s^2) + ((L + r) * \sigma^2)}$$

In this equation, μ now represents the period demand while s is the standard deviation of the lead-time, L. When combined with the average demand, its yield is the new base-stock equation used to determine the targeted inventory level at the start of each review period:[6]

Equation 4: Modified Base Stock Inventory Equation

$$BaseStock = \mu + z * \sqrt{(\mu^2 * s^2) + ((L + r) * \sigma^2)}$$

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[6] David Simchi-Levy, Philip Kaminsky, and Edith Simchi-Levy, Designing and Managing the Supply Chain, (McGraw-Hill Irwin, 2003) 62-63.

3.5 Application of Basic Model

In order to determine whether or not a periodic review model would improve the cost of inventory levels while maintaining or improving service level, a historical analysis using demand data from an eight-month period was conducted. The demand for vacuum circuit breakers is increasing, and ABB Sace only began to sell appreciable volumes of product beginning in January 2004. The historical data analyzed here considered the time period between January 2004 and the time of the analysis, October 2004. Because the vacuum circuit breaker product was first introduced in late 2003, the first two months of sales were much lower than the months between March and October when demand fluctuated yet kept a higher average. Therefore, only the months between March and October were used for analysis.

As mentioned in Section 3.1, inventory was held at both Ratingen and Dalmine and shipping time between the two took roughly five working days. Historical levels of inventory at Dalmine were pulled from the SAP records at random points in the months of which the analysis was being conducted. Historical levels of inventory in transit were determined from the average weekly demand multiplied by the transit time of 1 week. For determination of inventory at DECMS, historical forecasted values of embedded poles were used knowing that ABB Calor stocked to this amount at the beginning of every month and let the inventory decline over the period of the next four plus weeks. Therefore, the average inventory maintained in Ratingen was assumed to be half the forecasted value provided for that month by ABB Sace. In reality, this stock level may have been higher since DECMS began manufacturing this forecasted amount sometime during the month prior when the forecast was locked in.

Using the historical weekly demand, averages and standard deviations were applied in a spreadsheet to theoretical inventories in Ratingen, in transit, and in Dalmine. The stock in Ratingen represented the cycle stock for average demand in Dalmine plus safety stock to guard against variability in ABB Calor's order lead-time of four weeks. The transit stock calculation was modeled the same as for the historical level calculated previously. Stock in ABB Sace reflected the cycle stock from demand, as well as safety stock, to protect against fluctuations in transportation lead-time. Data for the variability in DECMS production time was not available, so an estimated standard deviation from the facility was used. The data for transportation fluctuation was available through the supplier management office in ABB Sace, but was only tracked one week out of every month instead of every week.

Because ITSCB tracked only on-time delivery of vacuum embedded poles but not service level of poles with respect to their own production, a range of safety factors was used in the model for comparison. Historical on-time delivery from Ratingen to Dalmine was only 89.6%, but because Dalmine carried high inventories of poles, the overall service level of the system might have been much higher. However, this assumption requires that the excess inventory of embedded poles in ITSCB are actually the ones required for current customer demand and not relegated to stock sitting idle waiting for future orders.

Once the theoretic periodic review model was developed in a spreadsheet, the theoretical inventory levels for historical demand were determined and compared to the actual historical levels using different safety factors. The inventories were compared on both a cost basis and also by comparing inventory turnover ratios. The inventory turnover ratio is determined using the equation:

Equation 5: Inventory Turnover Ratio

$$InventoryTurnoverRatio = \frac{AnnualSales}{AverageInventoryLevel}$$

Inventory models can easily be compared on a cost basis for identical time and demand periods, but as demand increases, inventories are also expected to increase. Comparing models across periods of different demand can be done effectively using the inventory turnover ratio that takes demand sales data into account.[7]

Results of the historical inventory analysis are provided in Table 2:

[7] Ibid 69.

Table 2: Historical Inventory Model Comparison

	% Service Level					
Measure	**90**	**95**	**98**	**99**	**99.5**	**99.79**
Inventory Value Actual	€ 2,112,859	€ 2,112,859	€ 2,112,859	€ 2,112,859	€ 2,112,859	€ 2,112,859
Inventory Turnover Ratio	**8.56**	**8.56**	**8.56**	**8.56**	**8.56**	**8.56**
Inventory Value Model 1	€ 1,159,828	€ 1,378,768	€ 1,625,184	€ 1,789,464	€ 1,939,813	€ 2,112,719
Inventory Turnover Ratio	**15.60**	**13.12**	**11.13**	**10.11**	**9.32**	**8.56**
Cost Difference	**€ 953,032**	**€ 734,091**	**€ 487,675**	**€ 323,396**	**€ 173,046**	**€ 140**
Ratio Difference	**7.04**	**4.56**	**2.57**	**1.55**	**0.76**	**0.00**

From the results, one can conclude that by using a basic periodic review inventory model, inventory levels and costs can be reduced between the two factories if the current service level to ABB Sace's downstream customer with respect to availability of vacuum embedded poles is less than 99.8 percent. Another advantage to the use of a periodic review type of inventory system is it allows the company to shape its inventory policy for a specified service level. Thus, the company can determine what service level is best for their business and can shape the stock levels accordingly. Currently, ABB Sace seems to have limited ability to tie stock level with service level. Although overall inventories can be lowered using this model, the allocation of inventory shifts dramatically with the factory in Ratingen assuming more of the cost.

3.6 Expanding the Model

After indicating that a periodic review inventory replenishment model could provide inventory cost savings compared to the current inventory management system, the project focused on enhancing the model for increased savings. To do this, two approaches are considered here: changing inventory placement and risk pooling; and investigating significant factors in the model. In attempting the first approach, analysis must rely on customer information received from DECMS regarding whom their other internal ABB customers were for the specific product types supplied to ABB Sace. Until recently, DECMS had sold common types of poles to internal factories in Poland, China, and Italy. But, a recent Business Area reorganization reduced to only three the number of common embedded pole types that are sold to circuit breaker factories in Italy and China. Because these pole types are high usage types at one or both of the internal customer sites, they could potentially be used to create savings through risk pooling.

Risk pooling seeks to take advantage of combining the variations of two different demands in determining safety stock inventory levels. If DECMS holds two separate safety stocks of common poles to guard against demand fluctuation for each customer, the total safety stock inventory level will be a summation of the two:

Equation 6: Base Stock Equation for Two Demands

$$BaseStock = \mu_1 + z_1 * \sqrt{(\mu_1{}^2 * s_1{}^2) + ((L_1 + r_1) * \sigma_1{}^2)} + \mu_2 + z_2 * \sqrt{(\mu_2{}^2 * s_2{}^2) + ((L_2 + r_2) * \sigma_2{}^2)}$$

For cases where the lead-time, L, the period, r, and the desired service level, z, are the same for both demands, combining the average demands and the standard deviations of the two separate demands into one safety stock equation results in a lower inventory requirement:

Equation 7: Risk Pooled Base Stock Equation

$$BaseStock \approx \mu_{1+2} + z * \sqrt{[(\mu_1 + \mu_2)^2 * s^2] + [(L + r) * (\sigma_1{}^2 + \sigma_2{}^2)]}$$

The base stock calculation is given as an approximation because it neglects the covariance factor that is typically small relative to the overall inventory level. Determining the covariance factor involves comparing period demand information between the two separate demands and can serve to either increase or decrease inventory levels depending on the relation of the independent demands. Similarly, by consolidating both factories' safety stocks into the downstream factory, in this case ITSCB, one can combine the standard deviations for supplier production time and for transportation time to reduce safety stock inventory.

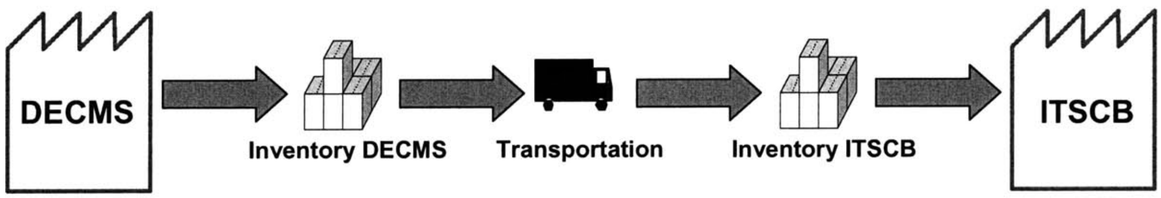
Equation 8: Base Stock Equation with Pooled Variability

$$BaseStock \approx \mu + z * \sqrt{[(\mu * (s_P{}^2 + s_T{}^2)] + [(L + r) * \sigma^2]}$$

where s_P is the variability of production lead-time and s_T is the variability due to transportation.[8]

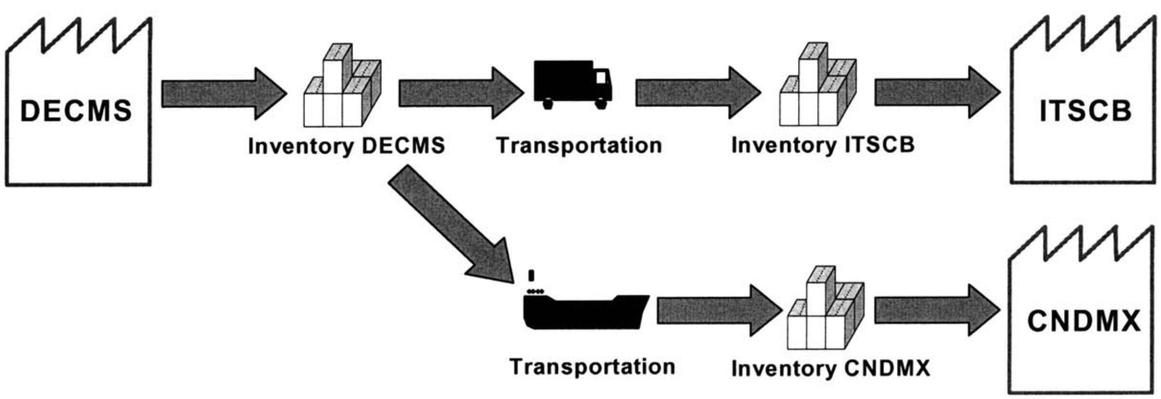
Knowing that some safety stock consolidation can lead to cost savings, three variations to the basic model were developed and compared. As explained previously, the basic model held safety stock located at DECMS to protect against production variation in Germany and had additional safety stock in Dalmine, Italy to guard against fluctuation in transportation. A representation of this model is displayed in Figure 12:

Figure 12: Inventory Model 1



The first model variant was the same as the basic periodic review model, except that safety stock for the three types of common poles would be consolidated at Ratingen and is represented in Figure 13:

Figure 13: Inventory Model 2



The second model considered the effects of moving all safety stock to the circuit breaker production facility in Italy as seen in Figure 14:

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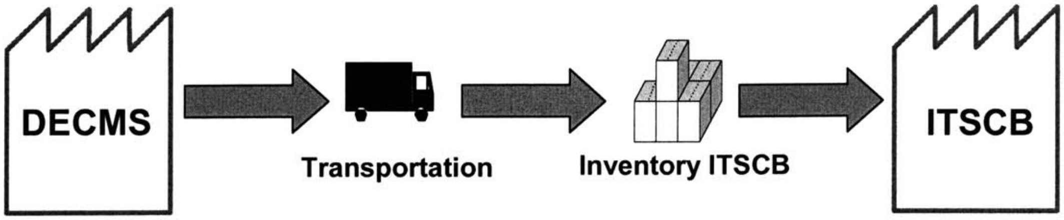
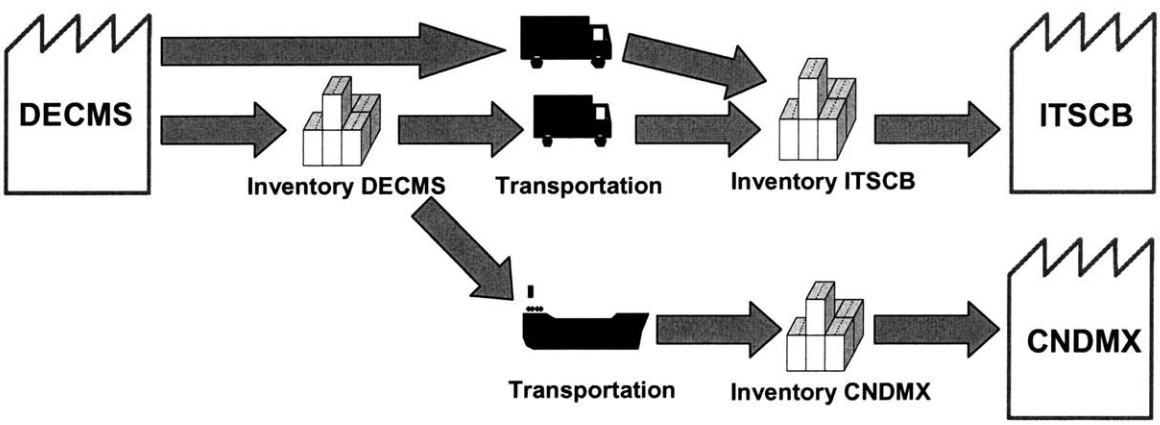
[8] Ibid 64-66.

Figure 14: Inventory Model 3



The last model considered combines the previous two by taking advantage of risk pooling for types of poles common to both China and Italy and by moving safety stocks for non-common pole types to ITSCB. This model is reflected in Figure 15:

Figure 15: Inventory Model 4



3.7 Model Comparison

Once these models had been added to the original Excel spreadsheet, inventory requirements were determined using forecasted demand levels for the upcoming quarter with historical standard deviation and an indiscriminately selected safety factor for a service level of 98%. In order to evaluate the risk pooling, the Chinese factory demand for the three common types of poles were included in the inventory calculations in models one and three. The results of this analysis are below in Table 3:

Table 3: Four Model Comparison

	Inventory Level (pcs)			Inventory Value (€)			Inventory
Method	DECMS	ITSCB	Total	DECMS	ITSCB	Total	TO Ratio
1	2125	1427	5712	€ 941,224	€ 629,650	€ 2,526,933	13.7
2	1956	1427	5544	€ 865,139	€ 629,650	€ 2,450,848	14.1
3	716	2158	**5035**	€ 317,222	€ 953,368	**€ 2,226,649**	**15.5**
4	1025	1910	5095	€ 450,083	€ 844,728	€ 2,250,870	15.4

The results of the comparison reveal that the inventory models three and four provide the lowest inventory cost with respect to sales demand level, with model three slightly outperforming model four.

When comparing the three models, it is apparent that model three will always be better than model one based on the safety stock calculations previously discussed. How model two compares to model three depends on the benefit of risk pooling the three common types of poles in Germany matched against the benefit of moving all types downstream to Italy. In total, ITSCB orders twelve types of vacuum embedded poles from DECMS in Ratingen, Germany. Two of the types shared with China are among ABB Sace's top three required poles. Overall the three common types of poles make up more than fifty percent of Sace's total demand. Because of this, initial expectations were that model two would yield a lower turnover ratio than model three. Model four was expected to provide the best overall solution because of its ability to take advantage of both risk pooling with the Chinese demand for common pole types, and to combine production and transportation variability for the remaining types.

What the four-model comparison shows is that safety stock inventory levels are highly dependent on the variation in supplier production and transportation, and that these factors outweigh risk pooling opportunities with demand for the Chinese plant. Unfortunately, neither of these variations is currently tracked accurately and both numbers were estimated. A sensitivity analysis was performed by increasing and decreasing the standard deviation for DECMS' production and the transportation. This analysis reveals that although the end ratios change, model three still provides the lowest inventory turnover ratio. Still, combinations of changing conditions of demand and variability in the system can lead to a shift in the model with the lowest inventory. This fact serves to weaken the legitimacy of the comparison while accentuating the value of quantifying data for on-time production and delivery. This comparison also points out that each model has inherent positives and negatives associated with it.

Some advantages of model one are that it requires only simple calculations and no consolidation of factory information is needed. Dalmine would also receive its orders in one week similar to their current model, so adjusting to the first model would be easier. Negatives to this model are that due to long production times at DECMS, most of the inventory will be held in Ratingen which might require additional storage cost. Due to the nature of its simplicity, model one will always carry more inventory than the other models.

Model two becomes more favorable as more factories demand the same types of poles as ABB Sace or in the event of increased demand variability, longer lead times, or longer review periods. However, similar to model one, model two dictates that more inventory be held at DECMS than models three or four do. Model two also requires consolidation of demand variability between the different factories having similar vacuum embedded pole types.

A characteristic of the model three inventory strategy is that it gives better results if demand volume increases without significant increase in demand variability. Drawbacks of the third model are that it places most of the inventory in Dalmine in the form of safety stock. Currently, ABB Sace keeps the inventory on the manufacturing floor. If demand increases and requires additional stock, ITSCB will require additional storage leading to more cost. As mentioned earlier, this model is heavily dependent upon measurement of DECMS production and transportation variability which currently are not measured. Initially ITSCB must also wait over four weeks for arrival of their orders once an order is placed in contrast to the one week it takes currently. From a model effectiveness standpoint, this extended delivery time matters little. However, in reality this attribute concerns ITSCB because it changes the current process and lengthens response time they perceive from DECMS.

Model four will always provide a better solution in terms of inventory cost than either model one or model two. Additionally, the model shares the burden of inventory between DECMS and ITSCB most equally. Yet, if demand rises or if the distribution percentage of demand shifts for the nine types of poles with safety stock held completely in Dalmine, this model has the same weakness as model three with regard to storage risk at ABB Sace. This model also combines the increased need for data gathering and analysis found in strategies two and three. Whether or not this plan is better than model three depends on the previously mentioned risk pooling benefit for the three common types of poles. As shown in Table 3, the inventory turnover ratios in both models three and four are very close. However, before choosing a model one needs to also analyze other factors that greatly impact the level of inventory and examples of these will be discusses in the following section.

3.8 Factors That Impact Inventory Levels

As alluded to in Section 3.6, there are two ways to improve the basic periodic review inventory model developed during the historical analysis. The first technique, considering inventory placement and risk pooling, was discussed in Section 3.7. The second manner is by changing significant factors that impact inventory levels and this will be addressed now.

3.8.1 Order Lead-time Reduction from Supplier

When reviewing the safety stock equation for periodic review,

$$SS = z * \sqrt{(u^2 * s^2) + ((L + r) * \sigma^2)}$$

the lead-time factor, L, greatly affects the level of safety stock and becomes more influential as demand variability increases. The order lead-time of vacuum embedded poles from Ratingen, Germany is four weeks, but initiatives launched at this facility are targeting order lead-time reduction to two weeks. Using the inventory models developed, the impact of this improvement can be assessed in Table 4:

Table 4: Four Model Comparison with Two Week Order Lead-time

	Inventory Level (pcs)			Inventory Value (€)			Inventory TO Ratio
Method	DECMS	ITSCB	Total	DECMS	ITSCB	Total	
1	1660	1427	5248	€ 734,310	€ 629,650	€ 2,320,020	14.9
2	1548	1427	5136	€ 683,693	€ 629,650	€ 2,269,402	15.2
3	630	1865	**4656**	€ 278,564	€ 823,335	**€ 2,057,958**	**16.8**
4	879	1708	4748	€ 385,383	€ 754,808	€ 2,096,251	16.5

As expected, the inventory turnover ratio increases for all models with model three still being the best solution. In fact, the level of improvement is greatest for model three when the order lead-time in Germany is reduced from four to two weeks. Reducing the lead-time causes the standard deviation of Ratingen production to be more significant than demand variability in the safety stock determination at DECMS. Both models three and four alleviate the safety stock due to this production variability by shifting the inventory to Dalmine and combining this variability with the transit deviation. Because the third plan alleviates safety stock for all types of poles, it improves the most with the lead-time reduction.

3.8.2 Reduction of Transit Time Between DECMS and ITSCB

In addition to reducing the lead-time from the supplier to the DECMS inventory location, further reduction can be made by focusing on the transit time between Ratingen and Dalmine. Currently, ABB Sace e-mails an order on Monday, DECMS receives the order variably Monday afternoon or Tuesday morning, and DECMS sends the order on a truck on Wednesday. ABB Calor pays for the delivery on a space-used basis with an outsourced carrier company. The company's truck stops at another location in Germany to pick up orders from other customers before departing for Italy. The truck travel time is usually between three and four days, so trucks leaving on Wednesday arrive in Dalmine for drop-off on the following Monday. So, the transit time between the two factories for orders is currently one business week plus one business day. With manipulations to the current system, transit time could be significantly reduced from one business day to one business week.

DECMS has the more expensive option of using a dedicated truck for deliveries to Dalmine. A dedicated truck can make the journey from Ratingen to Italy in only one day. Assuming one day for order placement, receiving, and loading and one day for transit, a transportation lead-time of two days can be introduced into the model. The impact of this reduction can be seen in Table 5:

Table 5: Four Model Comparison with Two-Day Transportation Time

	Inventory Level (pcs)			Inventory Value (€)			Inventory
Method	DECMS	ITSCB	Total	DECMS	ITSCB	Total	TO Ratio
1	2125	1276	5235	€ 941,224	€ 562,579	€ 2,317,311	14.9
2	1956	1276	5067	€ 865,139	€ 562,579	€ 2,241,226	15.4
3	716	2076	**4626**	€ 317,222	€ 916,816	**€ 2,047,546**	**16.9**
4	1025	1806	4665	€ 450,083	€ 798,742	€ 2,062,334	16.8

As before, all four cases are bettered with the reduction of the transit time between Ratingen and Dalmine due to the decrease of safety stock at ABB Sace. Model three still gives the highest inventory turnover ratio, but models two and three have improved the most because the overall impact of the Dalmine safety stock has decreased and the safety stock at DECMS becomes more prevalent. Therefore, the risk pooling provided in models two and four becomes more significant.

3.8.3 Change to a Bi-weekly Review Period

The previous two sections have aimed at reducing inventory levels by reduction in some facet of the lead-time. Another way to reduce safety stock inventory levels is to reduce the review period, and subsequently reduce the review period demand. As mentioned earlier, a weekly periodic review was assumed based on the current production practice of vacuum embedded poles in Ratingen, Germany. Production batches are started on Monday and run through until Friday or Saturday. On Sunday, the tube molds are cleaned and set up for production in the upcoming week. ABB Calor operates according to this schedule due to the length of time required to clean and change out molds, which is eight to ten hours for each mold.

When visiting the production facility in Ratingen, the production manager suggested that production runs of three days might be possible with smaller batch sizes, but mold changeover time made it impossible to conduct two production runs in one week. In order to convert to bi-weekly production runs and make a bi-weekly review period possible, DECMS would first need to develop a faster cleaning and changeover process. Running the simulations under these conditions shows the inventory cost benefit of changing from ordering once per week to twice per week as shown in Table 6:

Table 6: Four Model Comparison with Half-Week Review Period

	Inventory Level (pcs)			Inventory Value (€)			Inventory
Method	DECMS	ITSCB	Total	DECMS	ITSCB	Total	TO Ratio
1	1558	1140	4859	€ 691,497	€ 503,527	€ 2,151,083	16.1
2	1380	1140	4681	€ 609,855	€ 503,527	€ 2,069,441	16.7
3	580	1589	4330	€ 257,826	€ 702,603	€ 1,916,488	18.0
4	623	1454	**4238**	€ 274,053	€ 647,237	**€ 1,877,350**	**18.4**

Reduction of the review period is shown to have the greatest effect on all four strategies, but in this case model four gives the lowest inventory results. For this analysis, period demand variability is assumed to decrease at the same rate as period demand when going from weekly to bi-weekly review. In actuality, the standard deviation of demand may not behave in such a manner and could have a notable effect on the results of this analysis.

3.8.4 Results of Inventory Factor Impact

Discussion of both the reduction of system lead-times and shortening the review period show that targeting these factors can have an even greater impact on the level of inventory in the system than inventory placement and risk pooling. Reduction of the standard deviation of production and transit time could also have a noteworthy effect on the level of inventory in the system and exploring methods to reduce their inconsistency might also be cost beneficial. When changing the three factors analyzed, the third inventory model yielded the lowest inventory levels for reductions in production time at DECMS and transportation time while model four was better when switching to a half-week review period. The remaining question is which model provides the best solution if all three operational improvements are made? Table 7 shows that the inventory cost savings due to a reduced review period are more significant than the cost savings due to the other two factors combined, and thus, model four yields the highest inventory turnover ratio:

Table 7: Four Model Comparison with All Factors

	Inventory Level (pcs)			Inventory Value (€)			Inventory
Method	DECMS	ITSCB	Total	DECMS	ITSCB	Total	TO Ratio
1	1198	1053	4086	€ 531,167	€ 465,053	€ 1,809,729	19.1
2	1068	1053	3956	€ 471,454	€ 465,053	€ 1,750,016	19.8
3	494	1331	3659	€ 219,168	€ 588,030	€ 1,620,707	21.3
4	513	1249	**3596**	€ 225,041	€ 555,604	**€ 1,594,154**	**21.7**

Using the information from the previous analysis, an assessment of the value of operational decisions with regard to inventory costs can be made. Looking at the effects of these decisions for any of the models reveals the direct impact on inventory as shown in Table 8 for model four:

Table 8: Effect of Operational Decisions on Model 4

Action	Pole Reduction	Cost Savings	Ratio Change
2 Week Order LT	347	€ 154,619	1.1
2 Day Transit Time	430	€ 188,536	1.4
Bi-Weekly Review	857	€ 373,520	3.0
All	1499	€ 656,716	6.3

From this table, one can see where to focus initiative for operational improvements and that implementing all three actions would result in an inventory cost saving of €656,716. Reducing the review period has the greatest impact in terms of inventory cost savings, and this figure can be compared against the cost of changing to a bi-weekly review with two production runs per week in Ratingen. Some of these measures can be undertaken much faster and with more cost efficiency than others, and this analysis provides a tool on what measures should be taken and when. An analysis of the transportation savings tradeoff with respect to cost and ease of implementation is conducted in the following section. Looking further into the model comparison reveals that certain operational proposals have greater impact depending on the model being used. For instance, when utilizing model three, reducing the lead-time of production in Ratingen and shortening the review period have a greater impact than when using model four.

3.9 Cost Benefit of Reducing Transportation Time

As stated previously in Section 3.8.2, vacuum embedded poles are ordered from ABB Sace on Monday and are usually sent from DECMS on Wednesday. DECMS ships the poles via a shared independent carrier's truck that makes one stop at another location in Germany before traveling to Italy. The cost of the truck is determined at a set rate per 100kg that increases as ABB secures more space on the truck. As demand for ABB's vacuum circuit breakers increases, the shipping cost per pole has continued to increase as well. Because the dedicated truck is more expensive, costing over €1,125 for each shipment, the company has opted not to employ this method of transportation. However, ABB has not been able to equate the extra delivery time to the cost of additional safety stock due to the extra delivery cost. Using the model developed, it is now possible to make this comparison.

In order to make this analysis, the weights of vacuum pole shipments were estimated on a weekly basis using both historical and forecasted demand. Depending on the type of pole being shipped, either eighteen or twenty-eight poles are placed in each crate. The weight of a crate for each type of pole is available through the shipping department in Ratingen. Using this information with the demand data, the average weekly weight of vacuum embedded pole shipments between ABB Calor and Sace was found. For both the historical and forecasted amount, the rate per 100kg was used to determine the yearly cost of shipment for the poles using the shared truck delivery. The annual cost of the dedicated truck was multiplied by the rough number of fifty weekly deliveries per year.

The cost difference between these two delivery options are shown in Table 9:

Table 9: Transportation Cost Comparison

	Historical	Forecasted
Ship Weight/wk	**7722.2**	**10904.0**
Cost/100 kg	€ 6.80	€ 6.40
Shared Truck Cost/wk	€ 525.11	€ 697.86
Dedicated Truck Cost/wk	€ 1,127.50	€ 1,127.50
Cost Difference/week	**€ 602.39**	**€ 429.64**

Assuming that by using a dedicated truck and a faster order process the overall delivery time could be reduced to two days from the current week's time, the cost for the increased speed would be roughly €429.64 per week for forecasted future demand and would be €602.39 at the historical demand rate. Using fifty delivery weeks per year and varying rates for the cost of capital, the present value of the cost difference of decreasing delivery time is shown in Table 10:

Table 10: NPV of Transportation Cost Difference

Rate	Cost Difference
12%	€ 20,220
10%	€ 20,424
8%	€ 20,629
6%	€ 20,838

Recall that the inventory cost savings of reduced transportation lead-time from five days to two days for model three was €304,474. Therefore, regardless of the cost of capital rate used, the savings of using faster delivery in a periodic review system are substantial and should be considered. The dedicated truck could be contracted immediately, but a faster order process can also be effective in reducing inventory requirements. The factories in Ratingen and Dalmine have recently begun to share information about ABB Sace's orders and pole consumption. If Ratingen has access to Dalmine's weekly consumption information, early on Monday morning they can determine the number of poles required for stock period replenishment and can load the order the same day. The dedicated truck could arrive in Dalmine on Tuesday, be off-loaded in the afternoon, and received into Sace's ERP system. The operations in Dalmine would be unchanged and they would receive their delivery one week earlier.

Other factors to keep in mind are that as demand continues to grow a second truck may be needed which will increase delivery costs and could increase the difference in cost between the two types of delivery. However unless the current model parameters shift greatly, the safety stock cost savings due to a shorter delivery time will also increase at an expected rate greater than additional transportation costs. Regardless, the comparison analysis should be updated periodically as demand and transportation requirements and costs change.

3.10 Recommendations and Actions Going Forward

Either model three or four should provide substantial cost savings and a significant reduction in inventory management between the ITSCB and DECMS. Decisions should be based on warehouse storage availability at the two sites and the expected nature of demand growth at Dalmine, as well as in China and other factories supplied by DECMS. Once a final model has been chosen, the two factories should consider several actions to make the system more effective.

In the near term, the company should develop better data collection to measure standard deviation of transportation time and production time. Both of these factors greatly impact inventory safety stock levels in this model. As demand continues to increase, the standard deviation may also increase and it should be monitored often. ABB Sace should continue to share order information and consumption information, and should consider sharing their long-term production plan so that ABB Calor has a more forward plan of pole consumption. ABB Sace should realize that the model is still highly dependent on their three-month forecast levels and will have to ensure that their current forecasting method is consistent with best practice techniques. Additionally, ABB Sace should update their historical demand mix on a monthly or quarterly basis to set forecasts. The current mix being used is not consistent within the past ten months and actually places more weight on higher cost poles. From a service levels perspective, the factories should set the level high during implementation until a better level can be determined.

In the long term, ABB needs to work toward receiving and sharing order information from switchgear customers through ITSCB to DECMS to provide a more accurate picture of actual demand and enable better material planning at DECMS. ABB could consider tracking and incorporating correlation data for risk-pooled types of poles to provide a more accurate determination of safety stock levels. Another action the company should take is determining the best service level to use in the model. An analysis of the impact of lost or delayed sales due to stock-outs compared to inventory costs can help find an optimal level. At an advanced level, the service level optimization can be performed for each pole type as optimal service levels may vary depending pole demand volume and cost.

CHAPTER 4: COMPLETING THE CHAIN BY REVIEWING PROCESSES BETWEEN ITSCB AND CZEJF

4.1 Introduction

Where Chapter 3 detailed Dalmine's inventory and delivery methodologies with the internal upstream factory, this chapter will focus on the same issues with an internal downstream facility. For the twelve month period ending in September 2004, CZEJF was the principal customer of ITSCB apparatus for vacuum circuit breakers with greater than an 18% share of sales in terms of value as well as in volume. Recently, CZEJF expressed concern about a rising level of circuit breaker inventory at their site and the current four to five week lead-time from ABB Sace. Therefore, reviewing the order and delivery processes between the two factories was an important step in discovering potential delivery time and inventory reduction.

4.2 The Need for ITSCB Order Lead-time Reduction

As expressed in the introduction, the switchgear factory in Brno is seeking a reduction in delivery time for circuit breakers from ITSCB apparatus. The desire for reduction in CB order lead-time is based on the recent arrangement by EJF for the reduction in delivery time of their current longest lead-time item, the protection relay, from eight weeks to three weeks that is scheduled to occur early in the upcoming year. This reduction in lead-time will affect roughly forty percent of CZEJF orders and consequently, circuit breakers from ABB Sace with their four to six week delivery time will become the longest lead-time item for Brno. For these orders, the circuit breaker delivery will then be the production start time constraint for EJF switchgear manufacturing. EJF would like to see the delivery time of common circuit breakers currently at four week to be reduced to three weeks to match the delivery time of the protection relays.

4.3 The Order Delivery Process Between ITSCB and CZEJF

The switchgear factory in Brno orders circuit breakers from ITSCB based on specifications of each customer order. ABB Sace produces the breakers on a per order basis over the course of three to four weeks and sends them to the Czech Republic once per week on Tuesdays. Transportation is contracted through a shipping agency that picks up completed circuit breakers from ABB Sace's contracted warehouse near Dalmine, Italy. ABB Sace procures space on the common truck and pays on a weight basis. The shipment cross-docks at a warehouse in Oloumouc, Czech Republic, approximately 60-70 km from the factory in Brno, and is loaded on a truck for direct factory delivery. The weekly shipments are scheduled every Monday by ITSCB for circuit breaker orders that were completed the previous week. Shipping information and documentation is completed on Tuesdays in Dalmine and is forwarded to CZEJF. Shipments depart on Tuesdays and arrive at CZEJF by noon on Friday.

4.4 Excess Circuit Breaker Inventory in Brno

Based on the order and delivery process between the two factories, ABB Sace should hold, on average, an inventory of circuit breakers bound for Brno that is half the average demand for the Brno factory. Similarly, CZEJF should also average this same level of inventory during the week with high inventory on Friday afternoon and Mondays that is consumed during the week. Looking at CZEJF's historical order data, their average weekly demand for all types of circuit breakers from ITSCB is 46.7 breakers with a standard deviation of 59.3 and an average order size of 11. Given this average weekly order, one should expect that the average level of inventory at both locations should be a little higher than twenty-three breakers and a weekly high of nearly forty-seven. Dalmine's historical FGI count is not tracked with respect to shipments for Brno, but the average circuit breaker inventory in Brno was 266 breakers with a high of 606 and a low of 133. Even with the high standard deviation of weekly demand, one should not expect inventory levels averaging much over sixty pieces and high inventories above 110 breakers. This average level of inventory represents more than five and a half weeks of demand for CZEJF.

From another perspective, the production line takt time at CZEJF is 40 minutes. Running one shift per five day work week produces a maximum of sixty switchgear panels that at most could require one circuit breaker per panel. Operating two shifts gives a maximum panel production of one hundred twenty panels with a maximum of one hundred twenty required breakers per week. At normal demand, the factory in Brno works only one shift and extends or adds an additional shift for peaks in demand. Therefore, an average inventory of 266 circuit breakers constitutes over four weeks of orders if operating one shift at maximum capacity and more than two weeks if operating two shifts at maximum capacity.

One apparent reason for the accumulation of circuit breaker inventory at CZEJF, as well as the accumulation of inventory at the switchgear factory co-located with the apparatus factory at ITSCB, is the timing of circuit breaker ordering. Both factories place the order for the circuit breakers as soon as their project engineering departments determine the specifications. In cases when other material for the switchgear has a longer lead-time than circuit breakers, circuit breaker orders can occur seven weeks or more before the circuit breakers are required. Circuit breaker lead-times are four weeks for standard versions and up to six weeks for work intensive versions. At the point in time when the circuit breaker is ordered, the schedule for the switchgear production and the actual need date of the circuit breaker is seldom fixed. Orders usually shift out based on changes in capacity, availability of other material, or changes in customer specifications or requested delivery date. In these cases, the switchgear factories receive the circuit breaker order at the order date originally requested, but do not actually need them until some point in the future.

4.5 Inventory Reduction Through Order Process Revision

One potential solution to the order timing problem is for the factory in Dalmine not to lock in its production schedule until the week of production so that if customer delivery dates change, the customer is not forced to receive orders earlier. However, offering this type of delivery flexibility comes at some additional planning time cost if orders need to be continuously rescheduled as the downstream switchgear production plans shift. Additionally, if the switchgear customer makes changes in the circuit breaker requirements, the order between ITSCB and CZEJF must be changed which also requires transaction costs at both sites.

Upon further review, the actual placement of the order three or more weeks early when the switchgear order schedule is likely to shift does not seem to add any value in the overall chain. The necessary components for circuit breaker production in Dalmine are held as made-to-stock material and should be readily available for any incoming orders. Therefore, ITSCB has no need for receiving orders early from a component ordering perspective. Additionally, receiving orders early can lead to excess inventory if the switchgear schedule moves out and can lead to excess purchasing and order handling transactions if the customer changes their CB requirement in this time. Therefore, Brno should consider moving circuit breaker orders closer to their switchgear production start because the schedule is less prone to shift and the customer is less likely to make changes. The inventory problem could be mitigated by ITSCB apparatus allowing order date flexibility,

What seems to be important in this process is the information itself, not the placement of the order. As soon as the circuit breaker type can be determined, providing this information to both ITSCB apparatus and DECMS EP manufacturing with an approximate need date can provide them a window into the future for capacity scheduling but still allow flexibility in the event of a schedule or order change. Actual orders can be placed closer to the actual need date. A reduction in circuit breaker delivery time would provide even greater flexibility for customer and switchgear manufacturing changes because actual orders could be made even closer to the production start time. As long as the circuit breaker is not the longest lead-time item, an opportunity for increased flexibility and inventory reduction might lie in the development of better information sharing between switchgear factories and internal upstream supplier factories in Dalmine and Ratingen. However, as discussed in Section 4.2, forty percent of CZEJF switchgear orders will no longer have the issue of ordering circuit breakers too early, which will only occur when order specific special material with long lead-times are required or the order is placed well in advance of the requested delivery date.

4.5 Analysis of Delivery Processes

Because ITSCB produces circuit breakers to specific orders from CZEJF, the only inventory in the system is due to cycle stock. Thus, only two possibilities exist for reducing inventory in the system, reducing cycle stock and lowering inventory in transit. Cycle stock can be influenced by frequency of the deliveries between the two factories and transit inventory is affected by transportation time. The expected cycle stock held in both ABB Sace FGI and CZEJF pre-production inventory is equal to one-half the weekly demand. However, if deliveries are made more frequently, inventory has less time to accumulate at the FGI warehouse in Italy as well as at the storage point in Brno before it is used on the production floor. For instance, if deliveries are made twice per week on Tuesdays and Thursdays, then the expected inventory is only thirty percent of the weekly demand instead of fifty percent.

As of now, the transportation time for delivery is three days from the ITSCB warehouse to the factory in Brno using a shared carrier that cross-docks at a location in the Czech Republic. Using this carrier, ABB Sace has the option of sending two shipments per week at the contracted rates based on shipment weight. However, ABB Sace also has the option of contracting a dedicated truck that can make the journey in only two days time but at a higher cost of transportation. Knowing the average weekly cost of past shipments using a shared truck and the cost of a dedicated truck, a simple transportation model can be developed that factors in the cost of inventory at both factory warehouses and in transit in order to calculate total system cost. Once complete, the result of increasing the number of deliveries can be determined as is shown in Table 11:

Table 11: ITSCB - CZEJF Transportation Analysis

Deliveries	System Inventory Cost	
per Week	Shared	Dedicated
1	€ 263,410	€ 244,314
2	**€ 227,745**	€ 262,260
3	N/A	€ 313,742
4	N/A	€ 373,608
5	N/A	€ 416,706

The results of this analysis make two very interesting points. The first is that when total system inventory cost is factored in with transportation cost for the current frequency of one shipment per week, using a dedicated truck seems to offer a lower system cost than the current shared truck. Additionally, this model suggests that making two deliveries per week using the shared truck can provide the lowest system cost.

Another item to be considered is that CZEJF provides some circuit breaker component products to ITSCB apparatus and also a co-located ABB transformer factory currently supplies to ITSCB switchgear. At one time the two factories agreed to use a common shuttle for transportation of internal products and to share the cost of the truck. However, this agreement was suspended after an analysis focused on transportation cost revealed that high variability in order volumes made sending circuit breaker shipments with a dedicated truck cost ineffective compared to procuring space on a shared truck. Using this information and performing additional analysis on demand variability effects, transportation cost, and system inventory cost could significantly alter how many deliveries per week and what method of shipment provide the lowest cost.

CHAPTER 5: VIEWING THE ENTIRE VACUUM PRODUCT CHAIN

5.1 Introduction

After mapping the internal factory processes at apparatus and switchgear factories as well as upstream and downstream internal delivery processes, it was possible to work on creating a higher level value stream map that showed the order and delivery process across the entire internal value stream. Using a previously developed factory value stream map of the vacuum embedded pole production facility in Ratingen with the information acquired during this internship, the actual and value-added times were identified along the different stages of the chain.

5.2 Map Results

The extended value stream map shown in Appendix D is broken down into two loops, one for the processes involving vacuum embedded poles for the two upstream factories, DECMS and ITSCB, and one encompassing both ITSCB and CZEJF involving circuit breakers and switchgear. The reasoning for differentiating between the two processes is that vacuum embedded poles are now ordered by a mix of weekly forecast and stock replenishment methods in ITSCB that draws from established stock in DECMS. Therefore, the downstream order lead-time of switchgear is not directly affected by the upstream process time required for vacuum embedded pole delivery. Circuit breakers at ITSCB are made specific to from CZEJF orders and are in some cases directly affect the order lead-time of switchgear produced in Brno. The findings for the first loop is provided below in Table 12:

Table 12: External Value Stream Results for Vacuum Embedded Poles

EMBEDDED POLES

DECMS - ITSCB	Value Add	Actual
Order Time	3,4 days	8.0 days
Production Time	0.7 days	6.2 days
Transit Time	1.3 days	5.1 days
Total Time	5.5 days	19.3 days

The total order lead-time once an order is placed by ITSCB until the product is delivered in Dalmine is 19.3 days or nearly four weeks based on WIP counts along the many process stages. The value-added time for those process steps is only 5.5 days which is slightly more than one week and the percentage of total time committed to value-added time is 28.5%. Most of the actual time is related to order processing, but most of the lost time occurs during production. These results can be compared to those for the downstream stages in the chain that are shown in Table 13:

Table 13: External Value Stream Results for Circuit Breaker and Switchgear Orders

CIRCUIT BREAKER + SWITCHGEAR

CZEJF - ITSCB	Value Add	Actual
Order Time	1,5 days	15,2 days
Production Time	4.2 days	14.1 days
Transit Time	1.8 days	24.6 days
Total Time	7.5 days	53.9 days

The results of the second loop combine order and production times from processes across the ITSCB and CZEJF factories. The total time for switchgear delivery based on the ordering of circuit breakers is 53.9 days, nearly eleven weeks, compared to a value-added time of 7.5 days, one and a half weeks, which yields a percentage of time spent for value-added work of only 13.9%. Interestingly, most of the actual time in the process is transportation time between the two factories which are separated by only 900 kilometers. This time is mostly the result of the high inventory of completed circuit breakers in FGI at Dalmine and waiting for production in CZEJF.

The percentage of time for value-added work is much lower for the stage of circuit breaker production, delivery, and switchgear production that for the production and delivery of the vacuum embedded poles. Possibly more complex products downstream have led to a greater number of processes required to manage greater customization, number of components, and more personnel involved. As the number of process steps grows, wasteful action and WIP associated with each process step can also increase. Additionally, much of the time in the map points to inventory situated in delivery processes between ITSCB and CZEJF. Because circuit breaker production is made-to-order, FGI at these locations correlates to increased order lead-time if switchgear production schedules shift out. In contrast, inventory between Ratingen and Italy is held as replenishable stock at an increased inventory level specifically to reduce order lead-time due to variability in vacuum embedded pole production and transportation time. Therefore, inventory in this location does not factor into WIP time calculations and is a significant factor in the difference between the value-added time percentages between the two process loops.

5.3 Optimal Inventory Placement Across the Chain

Chapter 3 examined inventory reduction using a periodic review method for made-to-stock vacuum embedded pole replenishment between factories in Germany and Italy. Chapter 4 considered techniques for limiting made-to-order circuit breaker inventory between factories located in Italy and the Czech Republic. However, when looking across the value stream as a whole, one should determine optimal inventory placement for all factories in the chain. In many cases, holding inventory of finished products closer to the assembly of the final customer product can significantly decrease delivery time to the end customer. The trade off of holding stock of component finished goods is that for high cost items, too much money becomes tied up in inventory. For PTMV, the question is whether the current inventory strategy results in the lowest cost or if another approach is more economical. The Business Area could hold replenishment inventory with safety stocks of circuit breakers at Brno and safety stock of vacuum embedded poles in Dalmine. Other options would be having both products made strictly on a made-to-order basis or reversing the current model and allowing vacuum embedded poles to be produced as made-to-order and circuit breakers made-to-stock.

During this project, the opportunity arose to investigate this question with external consultants using proprietary software. The result of the software simulation was that the current proposed method of inventory management is the best solution for the PTMV Business Area. Looking at the products involved in the value stream between DECMS, ITSCB, and CZEJF, certain characteristics make holding higher inventories of circuit breakers cost ineffective.

Currently, ITSCB orders ten types of vacuum embedded poles from the factory in Ratingen which contribute roughly forty percent of circuit breaker cost. From these ten types of poles, the Apparatus factory in Italy produces twenty-six basic versions of vacuum circuit breakers. As described in Chapter 2, approximately 80% of circuit breakers produced in Dalmine require the assembly of standard customer options. The number of varieties of each basic type of breaker due to these options can increase from two to eight depending on the basic type. Therefore, the actual number of types of circuit breakers produced is closer to one hundred. In order to keep a replenishable stock of circuit breakers between Dalmine and Brno, the company would need to track demand data for each of these types and hold safety stock accordingly. One option is for basic breakers to be produced and held in stock at the switchgear factories and then customized with options at the time of order. However, this shift of location for circuit breaker finishing would require capital investments at switchgear factories as well as the development of new skill sets. If most demand was common to a relatively few types of breaker, safety stock could be held for these types and all other types could be made-to-order. Because this is not the case for PTMV, it is more economic for them to produce circuit breakers as made-to-order, thus making reducing circuit breaker order lead-time even more important.

Studying the entire PTMV value stream map, it is possible to calculate the combined value-added time of ordering, producing, and delivering both vacuum embedded poles and vacuum circuit breakers. For vacuum embedded poles, the value added time is only five and a half days while for circuit breakers, this time is less than three days which gives a total time of less than two weeks. Understanding this, the Business Area should investigate the feasibility of reducing order process times so that the delivery times of made-to-order products across the two upstream factories combined are close to the estimated value-added time of roughly two weeks. If this lead-time reduction is possible, the Business Area could rid itself of safety stock inventories for vacuum embedded poles resulting in a significant cost reduction across the chain. Although this would involve considerable effort in terms of both process improvement and order scheduling, the cost benefit may make it worth doing.

5.4 Managing the Dynamics of an Internal Extended Value Chain

The issues and suggested recommendations presented in Chapters 2, 3, and 4 can greatly impact the performance of the PTMV internal value stream as a whole. In addition to these subjects, another noteworthy concern of vertical supply chains in the bullwhip effect. The bullwhip effect occurs as each facility in a vertical supply chain alters the picture of actual end customer demand due to several reasons. Factors that can contribute to greater demand variability upstream are increasing lead-time, poor forecasting, batch ordering, and price fluctuations.[9] Variability of demand tends to increase the further up the vertical chain one travels requiring factories at the top of the chain to carry higher safety stock inventories to satisfy this greater fluctuation.

In order to best reduce the bullwhip effect in a vertical supply chain, companies must try and understand the major factors causing increased variability. Perhaps one of the easiest and most effective ways to decrease this effect is sharing demand information with factories upstream in the value chain. Currently, ITSCB only sees the end customer demand for circuit breakers after downstream switchgear factories spend time processing the order through their engineering stages and decide to physically place the order. The vacuum embedded pole factory in Germany currently is provided a monthly forecast from Dalmine, but under a periodic review system would only see the direct consumption of poles by ITSCB. In theory, both upstream factories could have a relatively high visibility of what vacuum embedded poles will be needed at the time a customer places a switchgear order. Although some engineering work is sometimes necessary to determine the options required for circuit breakers, the basic type of breaker and its vacuum

[9] Ibid 103-104.

pole requirements are often known much earlier. Production schedules and consumption data from both downstream factories could be shared back to the factory in Ratingen.[10]

From a strategic standpoint, another method of limiting the bullwhip effect is limiting the number of factories in the internal supply chain. Reducing lead-times through process refinement and limiting production and shipping delays by superior order management are also beneficial in keeping variability from growing upstream. Spikes in downstream variability due to prices promotions and special sales can have a major affect of demand variation upstream and so should be restricted. Other strategies include techniques such as vendor managed inventory (VMI) that allows the upstream facility to control the inventory levels of their product at the downstream factory.[11] The PTMV Business Area should determine their major sources of the bullwhip effect and take appropriate measures to address them.

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[10] Robert Hayes, Gary Pisano, David Upton, and Steven Wheelwright, Pursuing the Competitive Edge, (John Wiley and Sons Inc., 2005) 163-164.
[11] David Simchi-Levy, Philip Kaminsky, and Edith Simchi-Levy, Designing and Managing the Supply Chain, (McGraw-Hill Irwin, 2003) 109-110.

CHAPTER 6: IMPACT OF ORGANIZATIONAL FACTORS ON IMPLEMENTATION OF OPERATIONAL CHANGE

6.1 Introduction

> *"Even when confronted with comparative data that show the clear superiority of another approach, managers of lagging facilities often will resist the idea of adopting that superior practice, arguing that their particular facility has special requirements or constraints that make adoption impractical. Occasionally, such a stance is well-founded. More often, however, the resistance of a facility's managers reflects a defensive attitude and a concern that adoption of another facility's practices is an admission of their own shortcomings."*[12]

The successful implementation of any project requires effective change management within the organization. The method of initiating and conducting change needs to fit the company's strategic, political, and cultural identity and work through key personnel for best results. In the case of value stream improvements across several different factories, a company can either push operational change from higher level management or attempt to grow this change from individuals units at the bottom. Understanding the corporate organization with its strengths and weaknesses should drive strategic decision making and the mode of execution.

6.2 Historical Overview of ABB

Most of the individual plants that comprise a Business Area became a part of ABB through merger and acquisition. ABB purchased several small factories across several different countries in order to gain entry into new markets. The company has undergone several reorganizations in order to streamline operations and reduce competition between similar plant sites. Previously, a plant in one country may have produced all the sub-components needed to make the fully

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[12] Robert Hayes, Gary Pisano, David Upton, and Steven Wheelwright, Pursuing the Competitive Edge, (John Wiley and Sons Inc., 2005) 156.

integrated end product that was customized for their region's market. Individual plants in other countries were also fully integrated and served their own market's special requirements. However, as these factories worked to increase their market size through expanding their regional sales, they came in competition with sister factories.

Recently, the Business Areas have moved from horizontal factory structures to vertical structures in which individual factories specialize in certain products in the value chain. Factories have changed from being independent, fully integrated sites to internal suppliers and customers of plants that were previously their competitors. ABB wants to reduce the number of products in each factory to achieve lower cost production and other advantages of product specialization. In addition to a vertical factory structure, ABB also organizes factories through a geographic region strategy in which groups of vertically aligned factories serve specific areas of the globe.

6.2 Tradeoffs and Challenges of the Global Vertical Network

By moving to a vertical factory network that specializes factories by process stage, ABB has positioned itself to achieve certain operational advantages, but also faces many inherent structural challenges. Aligning plants by process stage allows factory managers and workers to develop expertise for one specific product or group of products. This specialization lets managers focus "on a narrow set of operating goals, problems and processes"[13] pertaining to a few products instead of many with the intent of managing a few products exceptionally well instead of many products merely adequately.[14] Allowing a factory to develop an area of expertise can result in higher quality, better manufacturing processes, and faster implementation of newer products.

Another advantage of aligning by process stage is that factories can better take advantage of economies of scale. Fewer products allow factories to have less variation in production equipment, less time lost to line changeovers, and longer production runs between equipment changeovers. This leads to lower product manufacturing cost at each product step across the

[13] Ibid 141.
[14] Ibid 141.

value stream. Organizing facilities by process stage also allows companies such as ABB to benefit by strategically aligning different stages of production at facilities where employee skills, cost structures, or technical expertise are already located. Production processes that are highly labor intensive can be staged in regions with lower labor costs, those that require engineering intensive activity may be situated closer to areas with better university support, and other factories could be located near sources of raw materials to benefit from lower cost or faster delivery times.

A challenge that arises for vertical factory structures focused by process stages is the production scheduling of individual products across a network of many factories. Establishing, coordinating, and enforcing production schedules of several facilities is management intensive and most likely requires a centralized operations group that can direct these functions. When schedules are not met by upstream plants, downstream production facilities often have to push their delivery schedules which results in late delivery to the final customer. Likewise, if customers alter their order requirements or shift requested delivery dates, these changes must be effected through multiple facilities instead of only at one site. This inherent scheduling complexity across multiple factories means that a vertical factory structure will nearly always be less effective in satisfying the ultimate customer in terms of order flexibility and order delivery. In order to limit the impact of scheduling and delivery problems and reduce delivery time in a value chain, factories usually carry inventory of products from upstream suppliers. In contrast to horizontally aligned, independent factories, a vertical structure requires the transportation of products between facilities. Because of these factors, vertically oriented companies will have higher transportation and inventory costs due to the nature of their organization.[15]

By globally positioning vertically aligned groups of factories, ABB is able to tailor their final product for specific customer needs in different regions of the world. Establishing similar process stage factories across many localities also provides the benefit of internal supporting factories that are closer to each other so that delivery times are shorter and required inventories may be smaller. An example of this for PTMV are circuit breaker production facilities located in both Asia and Europe that supply ABB switchgear facilities in the same regions. An exception

[15] Ibid 144.

of this strategy is that PTMV has only one manufacturing site located in Europe to supply vacuum embedded poles for circuit breaker factories across the globe, so factories in regions outside of Europe must keep higher inventories to offset the longer delivery times.

6.3 Characteristics of a Centralized Network

Synchronized with their transition from a horizontal to a vertical factory structure, ABB is moving from a decentralized to a more centralized operations network. A decentralized network offers individual sites greater autonomy while a centralized network seeks to standardize processes to a corporate norm. Centralized networks are useful for establishing standardized products across factories in different locations. Product uniformity across different regional markets can be attractive for customers that also work in many countries if they are also trying to centralize their operations.

Highly coordinated organizations can make sure that best practices for processes such as scheduling, production, product development, and testing are implemented throughout all factories to yield an overall high operational efficiency. The implementation of new methods for many factories is faster if current functions are standardized. Similarly, centralized functions can limit the redundancy of resources allocated to functions like research and development, product design, supplier management, and process development for a group of factory sites. While facilities in decentralized organizations focus on local operational optima, centralized networks can work to develop global optima that are more cost efficient. Lastly, a centralized structure pushes individual sites to adopt corporate ethical policies and standards. Overall, a more centralized operational network seems to be more practical for companies that are vertically structured by process stage.

Disadvantages of a highly focused and coordinated corporate initiative are that as products become more standard, specific customer needs are less easily addressed. Strongly centralized networks inhibit the ability of single plants to develop their processes in order to take advantage of local conditions and constraints. Likewise, processes and strategies that result in high operational efficiency in one area of the world may not yield similar efficiencies in other countries. Decentralized networks also create an environment of creativity where individual sites can experiment and continue to develop better procedures where centralized networks can become stagnant.[16]

6.4 Impacts of ABB's Operating Network Decision

Certain network characteristics are more beneficial in specific business environments, and a company's operating network is most effective when aligned with the company's overall business strategy. For instance, horizontal structures better fit production that is "less complex and capital intensive"[17] and whose production volumes are not suitable for economies of scale. This type of network best addresses customers that require greater flexibility, responsiveness, and product innovation.

Because vertically oriented networks result in lower production stage cost along with lower flexibility, they are advantageous when satisfying customers who value low cost over rapid delivery or order customization. These networks are also beneficial for intricate and rapidly changing specific process technologies that require specialization at certain stages along the chain.[18] The current ABB approach is most effective for "complex, divisible, and capital-intensive processes"[19]

As mentioned previously in Section 6.2, vertical structures can incur many additional costs if not managed effectively. Higher transportation and inventory costs are inherent in this type of structure, but missed schedules, late deliveries, and lengthy stage process times along the value chain can result in even higher inventories. Also, central overhead costs may rise due to management requirements of coordinating operations across an extended network. If these costs become too great, they offset one of the key advantages to a vertical factory structure, which is

[16] Ibid 154-156.
[17] Ibid 152.
[18] Ibid 147.
[19] Ibid 153.

lower production cost. In the case of the PTMV Business Area, these added costs are recognized and this project is an example of the efforts currently in place to reduce these costs.[20]

The goals of the project were aligned with those of the Business Area after its change in strategic design. Improved inventory management between internal factories is part of an effort to look beyond what is best for individual factories and work to a Business Area optimum where companies share risks and costs and inventories are minimized. Likewise, reducing order lead-times at individual sites throughout the internal value stream will reduce overall product delivery time to the end customer and reduce inventory costs related to WIP in the system.

6.5 Aspects of Change Management

Individual factory culture is an important facet of the overall culture in ABB and should be recognized as such in operational planning and decision making. As a result of the merger and acquisition history, factories have a strong sense of individual identity and pride. Most of the facilities still keep the factory name they held before being purchased by ABB. For instance, in Dalmine, the factory is still referred to as ABB Sace and in Ratingen the factory is called ABB Calor. The factories have traditionally hired from the local area and management was grown from the lower ranks or also brought in from nearby regions. In addition to each factory having developed its own identity, there also exists a national pride in each plant. Workers in factories view themselves foremost as members of their individual plant, secondly as citizens of their country, and lastly as employees of the company. Differences in language and customs will always exist and can create delays and potential misunderstanding for all communications between both individual plants and also between the Business Area and production facilities.

The cultural and political environment in PTMV was shaped not only by the fact that many of the factories became ABB through merger and acquisition, but also because the Business Area is moving from a decentralized horizontal structure. For this reason, the new centralized vertical operational structure in the Business Area clashes with the traditional culture of the company.

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[20] Ibid 152-153.

How PTMV manages operational changes that align with their current structure will be paramount to the success of the Business Area.

> *"A network's overall effectiveness therefore requires not only that each individual facility within be managed effectively, but also that they all be buttressed with effective overall network policies and strategies. Unless a company deals with their issues proactively the advantages of multi-facility operations can be quickly dissipated in a tangle of complexity and confusions"*[21]

The cultural factors and past strategic alignment seem to indicate that change management is best grown from within individual factories up through the Business Areas. Pushing change from top level organization may be met with resistance and would seem to be a slower process. The individual plant managers in this environment seemed to have a fair amount of power and are key to any implementation that is initiated in or across factories. However, the vertical structure currently employed requires a certain level of centralized control and standardization that must be pushed from the Business Area itself.

Impressions from this project indicate that this is the approach that ABB is currently using. The Business Area did not seem active in pushing their agenda and were relying on creating incentives to spur management cooperation from within. The company has tried to link rewards for individual factory managers to Business Area performance and is still working to improve in this area. However, many performance measures for lower level managers still dictated by ABB policy seem to encourage individual factory performance over that of the Business Area as a whole. Another strategy that ABB appears to be trying to implement is placing new managers at factories from outside their traditional homegrown talent pool to establish a corporate identity and company culture at each site. A final strategy is the development of the CRC itself as an internal consulting group to spread company knowledge, practices, and culture across different manufacturing locations.

[21] Ibid 142.

The CRC was a very interesting political player in this process for many reasons. The CRC is working for the Business Area with respect to a global approach to inventory and order lead-time issues. However, the CRC is also a client of the individual factories and their success depends upon these factories using them for operational improvement projects. Thus, the CRC must maintain a good relationship and reputation with plant managers and can only apply limited pressure for the acceptance of the Business Area initiative. The CRC tries to gain factory trust through successful projects and then leverage this success and established trust to push for cross-plant cooperation.

CHAPTER 7: PROJECT CONCLUSIONS

7.1 Recommendations Overview

Based on their strategic vertically aligned organizational structure, ABB needs to take steps to reduce the individual stage product lead-times and to reduce inventories between factories. At the circuit breaker factory in Dalmine, they can reduce product lead-time by reducing the production scheduling period to less than one week in order to make the flow of orders more continuous before reaching the manufacturing floor so that they are processed as individual orders instead of as batches of orders. They can further reduce their order time by reducing the physical distance between launch stages, making the information transfer more efficient, and better coordinating pre-assembly operations with basic circuit breaker production. Inventory costs and production lead-time can be reduced by establishing WIP control on the factory floor.

Vacuum Embedded Pole inventories between Ratingen and Italy should be managed through a periodic review inventory replenishment model. If not cost prohibitive because of additional storage requirements, this model should be designed so that all safety stocks are held at the point-of-use factory in Dalmine. Otherwise, the model should take advantage of the inventory risk pooling opportunity for poles that are also produced for the circuit breaker factory in China and hold safety stock of common poles in Ratingen. Safety stock for ITSCB specific poles should then be stored in Dalmine. Both factories should strengthen their data tracking with respect to numbers needed for the inventory model in order to have the most accurate stock levels possible. The transportation time of vacuum embedded poles between the two factories can be quickly reduced by using a dedicated truck for pole delivery and reducing the order processing time. The order process between the two factories should become less manual and more responsive by more fully utilizing the information sharing that is now taking place. The cost benefit of reducing the order lead-time and shifting toward half-week production runs in Ratingen should be further explored to see if allocating resources is viable.

In cases where circuit breakers are not the longest lead-time items for switchgear production, orders between the switchgear factory in Brno and Dalmine should be placed later rather than sooner to allow for shifts in the switchgear production scheduling and customer changes. Although the orders to Dalmine will be placed later, order information from the switchgear factory should be shared as soon as possible with the factories in both Dalmine and Ratingen. The basic circuit breaker and vacuum embedded pole requirements are available early in the switchgear order process and can help the upstream factories plan material and scheduling capacity. A more in-depth study of the transportation method between Dalmine and Brno should be conducted to include all ABB materials shipped between the two factories taking into account both shipping and inventory cost. By sharing trucks and increasing delivery frequency, there may be an opportunity to reduce costs and speed delivery between the two factories which might also include products from other Business Areas.

7.2 Cultural Dynamics at ABB

During my internship, I visited four different ABB facilities in four different countries and observed the individuality of each factory from both a country and community standpoint. In many factories I saw performance data for the factory itself, but never witnessed a factory posting the Business Area performance results. Encouraging employees in these factories to identify themselves as member of a Business Area or corporate team instead of lone factories is a difficult and significant challenge for ABB in its vertical network structure. Substantial effort needs to be expended on aligning incentives and building teamwork across factories if global efficiencies are to be achieved.

I also gained an appreciation for the difficulties of operating in a multinational company with a mix of culture and language. Even with a common corporate language, communication cannot be taken for granted. Cultural interpretation and mannerisms compounded with great distances between factories can easily lead to miscommunication and misunderstandings. Effective communication is one the most important facets of successful business, and global companies will always have a disadvantage in this area. However, time lost to understanding and clarification is balanced by the gain of a greater variation of innovative ideas and the increased number of skills that a company acquires as it expands into new cultures.

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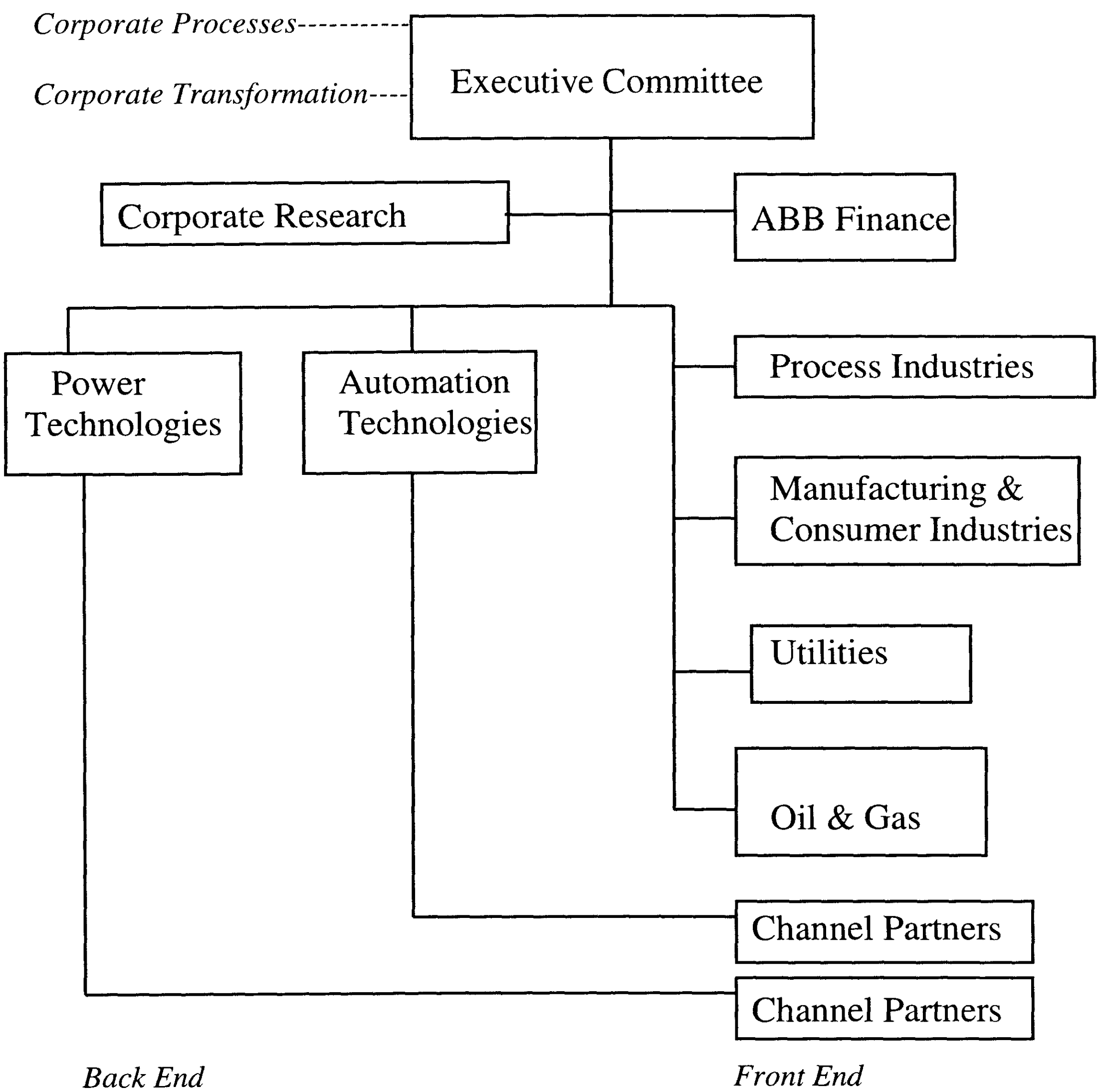
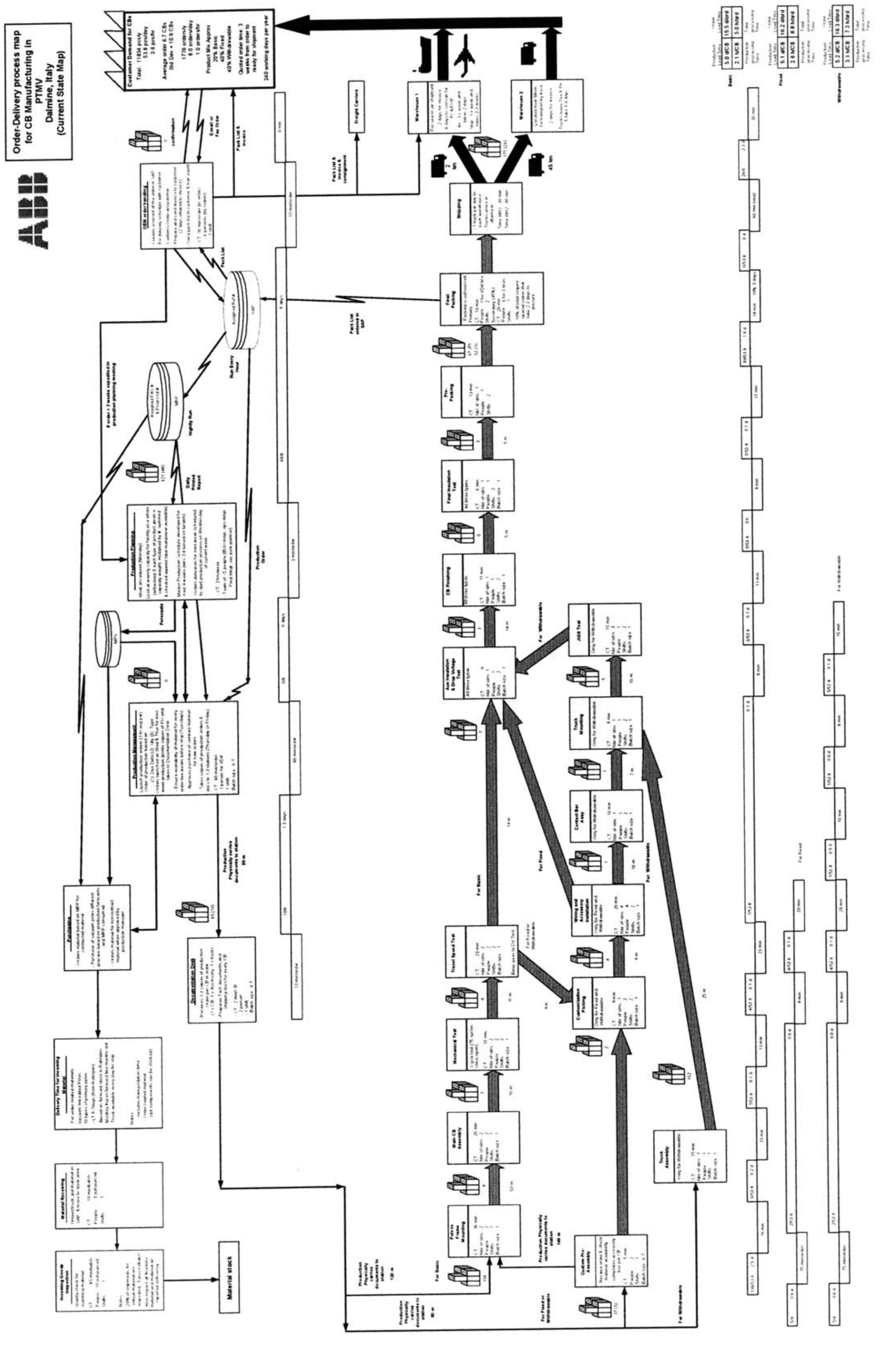
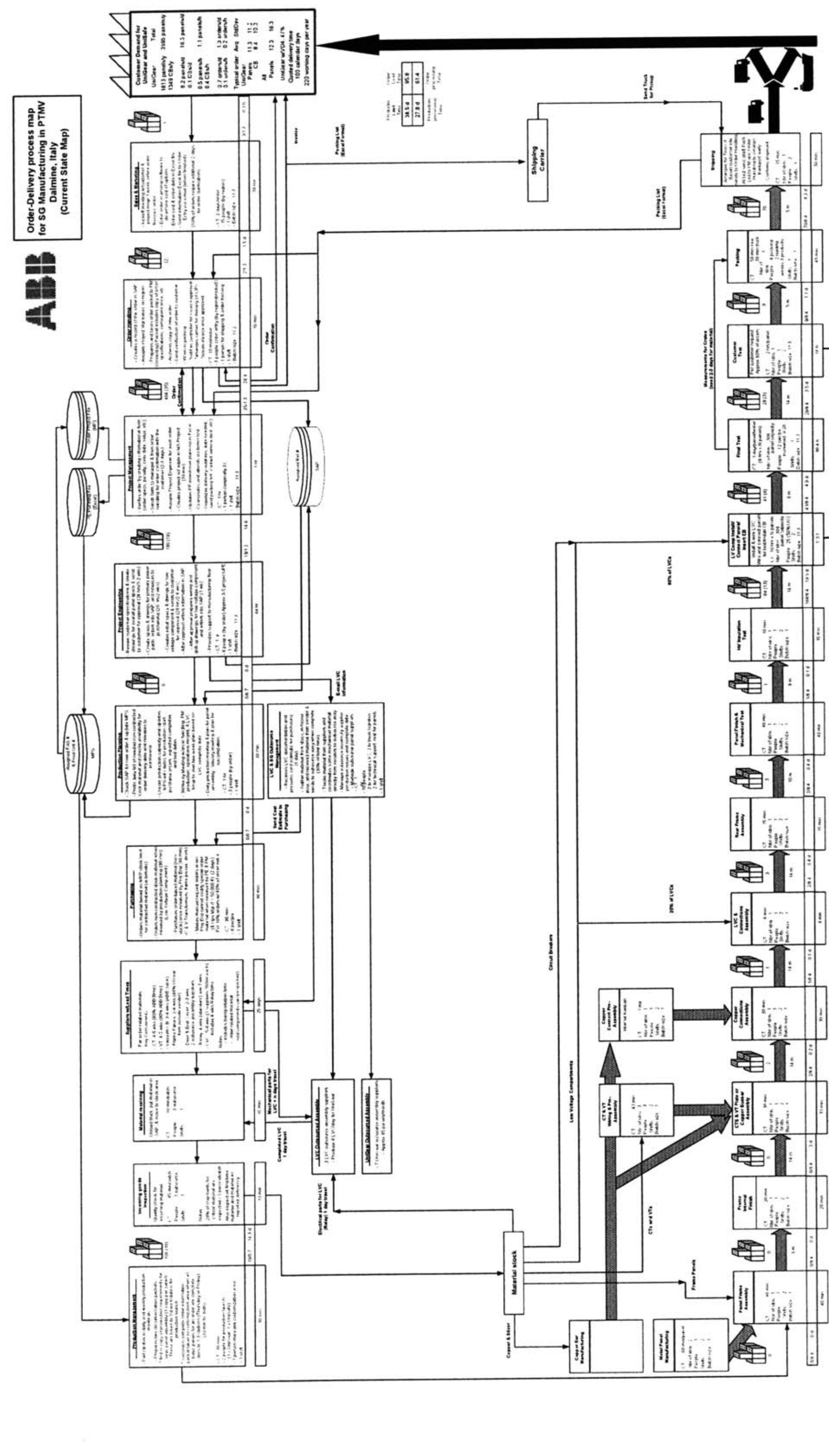
Appendix A: ABB Front/Back Structure



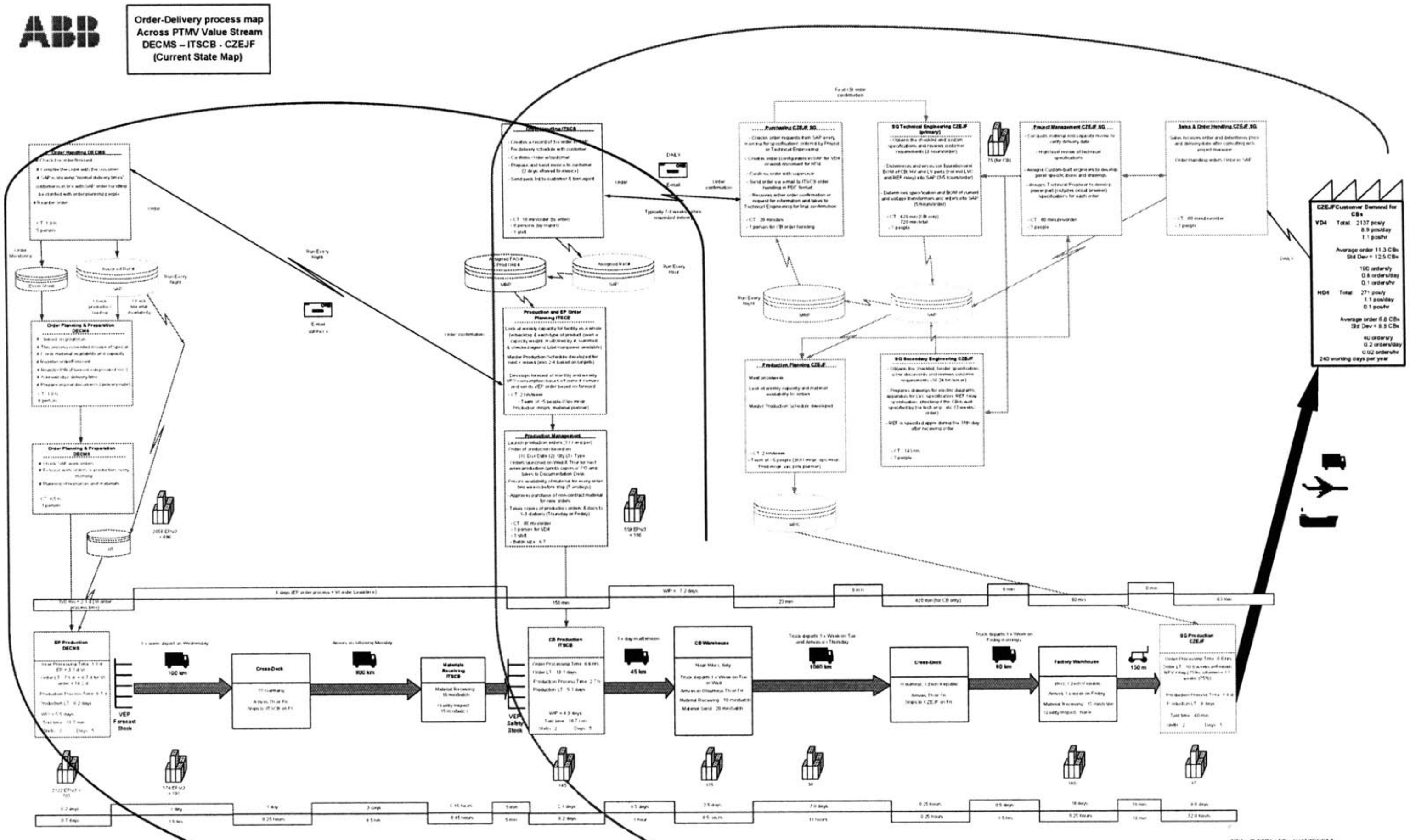
Appendix B: Apparatus Value Stream Map



Appendix C: Switchgear Value Stream Map



Appendix D: PTMV Vacuum Product Value Stream Map



EMBEDDED POLES

DECMS - ITSCB	Value Add	Actual
Order Time	3.4 days	8.0 days
Production Time	0.7 days	8.2 days
Transit Time	1.3 days	5.1 days
Total Time	5.5 days	19.3 days

CIRCUIT BREAKER + SWITCHGEAR

CZEJF - ITSCB	Value Add	Actual
Order Time	1.5 days	15.2 days
Production Time	4.2 days	14.1 days
Transit Time	1.5 days	24.6 days
Total Time	7.5 days	53.9 days

Appendix E: Simul8 Model for Circuit Breaker Production Line