DESIGNING A SUPPLY CHAIN FOR A FOREIGN GREENFIELD FACILITY

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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ABSTRACT

ABB Schweiz AG has experienced substantial growth in demand for the innovative energy management and conversion products designed and assembled by the Medium Voltage Automation Products Division. This demand has fully consumed the capacity in their assembly facilities worldwide and has driven the organization to initiate planning of a ten thousand square meter assembly facility in Lodz, Poland. This thesis focuses on the design and implementation of the supply chain for the new facility. By utilizing supply chain optimization concepts, the network of hundreds of suppliers, two warehouses, and multiple assembly and test locations has been optimized. This thesis details the application of theoretical models, such as the economic order quantity model, continuous review inventory policies and generalized power rule forecasting, in the development of inventory management guidelines for the Greenfield facility's supply chain. Additionally, the document details the practical challenges associated with implementation including customs clearance, business plan development, supplier involvement and packaging strategy.

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BIOGRAPHICAL NOTE

Brian Anstey was born in Kansas City, Missouri and has lived in Singapore, Hong Kong, Switzerland and various parts of the United States including New York, Illinois, Michigan and Ohio. Brian holds a Bachelor of Science in Operations Research and Industrial Engineering from Cornell University and a Master of Science in Industrial Engineering from Northwestern University. Prior to joining the Leaders for Manufacturing program at MIT, Brian worked for General Motors. While at GM, Brian held a number of positions of increasing responsibility within the Industrial Engineering organization before becoming the Lead Industrial Engineer at the Lansing Delta Township Assembly Plant, a $1.2B Greenfield facility. A veteran of 5 vehicle launches, Brian was recognized with the 2007 Young Leader in Manufacturing Award by the Society of Automotive Engineers for his contributions to plant productivity, quality improvement and operational transformation.

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1 Company Background and Introduction

1.1 Chapter and Thesis Introduction

This chapter provides background on the history and business of The ABB Group, an overview of the operations in Turgi, Switzerland and an introduction to the products produced at the site. Additionally, this chapter introduces Project Splügen, the project to establish a Polish Greenfield assembly facility that this thesis is based upon. This thesis is based on the development of the supply chain and inventory management strategies associated with this venture. Through the course of the thesis topics such as economic order quantities, demand forecasting and safety stock will be introduced as they pertain to this project. Finally, a three lense analysis introduces some of the cultural and strategic challenges associated with Project Splügen[1].

1.2 The ABB Group

The ABB Group was founded in 1989 when the Swedish power company, Asea and the Swiss Brown Boveri & Cie. (BBC) merged. In that same year, ABB acquired over 40 companies to become a leader in the fields of power and automation products. ABB carried on its tradition of acquisition and innovation until the present day growing to employ 120,000 people in over 100 countries. In 2007 ABB earned $29.1B US in 2007[2]. Today that ABB group is organized into five divisions:

Power Products

"Power Products are the key components to transmit and distribute electricity. The division incorporates ABB's manufacturing network for transformers, switchgear, circuit breakers, cables and

[1] The ABB Medium Voltage Drives and Power Electronics business unit names projects based on Swiss mountains. In this case, the business unit chose the name Splügen as the project title. The author uses the name Splügen to refer to the project and facilities or teams associated with the project.

[2] The ABB Group. (n.d.). The ABB Group Homepage. Retrieved February 13, 2009, from http://www.abb.com/cawp/abbzh252/a92797a76354298bc1256aea00487bdb.aspx

associated equipment. It also offers all the services needed to ensure products' performance and extend their lifespan. The division is subdivided into three business units".[1]

Power Systems

"Power Systems offers turnkey systems and services for power transmission and distribution grids, and for power plants. Substations and substation automation systems are key areas. Additional highlights include flexible alternating current transmission systems (FACTS), high-voltage direct current (HVDC) systems and network management systems. In power generation, Power Systems offers the instrumentation, control and electrification of power plants. The division is subdivided into four business units."[1]

Automation Products

"This ABB business serves customers with energy efficient and reliable products to improve customers' productivity, including drives, motors and generators, low voltage products, instrumentation and analytical, and power electronics. More than one million products are shipped daily to end customers and channel partners, spanning a wide range of industry and utility operations, plus commercial and residential buildings."[1]

Process Automation

"The main focus of this ABB business is to provide customers with integrated solutions for control, plant optimization, and industry-specific application knowledge. The industries served include oil and gas, power, chemicals and pharmaceuticals, pulp and paper, metals and minerals, marine and turbocharging. Key customer benefits include improved asset productivity and energy savings."[1]

Robotics

"ABB is a leading supplier of industrial robots - also providing robot software, peripheral equipment, modular manufacturing cells and service for tasks such as welding, handling, assembly, painting and finishing, picking, packing, palletizing and machine tending. Key markets include automotive, plastics, metal fabrication, foundry, electronics, machine tools, pharmaceutical and food and beverage industries. A strong solutions focus helps manufacturers improve productivity, product quality and worker safety. ABB has installed more than 160,000 robots worldwide."[1]

1.3 The Turgi, Switzerland Site

Turgi, Switzerland, located 30 km Northwest of Zurich, is the home to the Medium Voltage Drives and Power Electronics business unit. The $1B US business unit, which belongs to the power products division, has global responsibility for the ACS family of Medium Voltage AC Drives, Bordline Traction Converters, and future generation of wind converters amongst other electrical conversion products. ABB's Turgi site houses the business unit's administrative, research and development, sales and service organizations. Additionally, the business unit conducts a portion of its assembly operations and its entire final testing activity at the site.

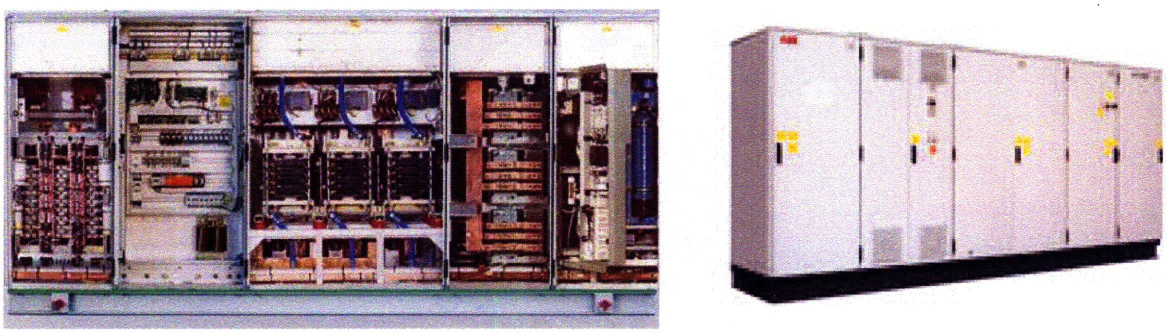


Figure 1: The ACS 6000 Medium Voltage AC Converter

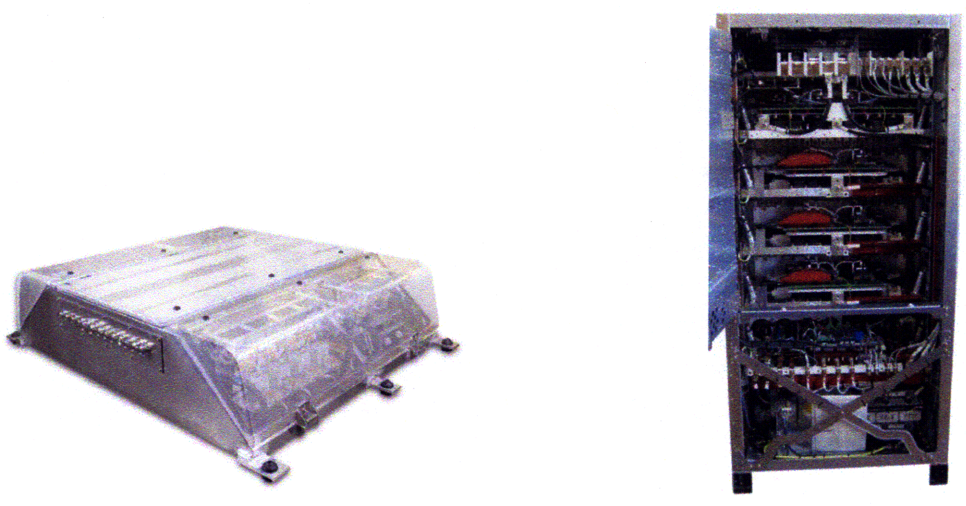


Figure 2: ABB's Bordline Traction Converters

1.4 Project Splügen Background

The goal of ABB Switzerland's Splügen Project is to establish a Greenfield assembly facility in Lodz, Poland. This venture was undertaken to address the capacity bottlenecks in the business unit's existing assembly facilities in Turgi, Switzerland. To date, three product lines have been identified to be relocated to Poland: The ACS 6000 Medium Voltage Converter, the power electronics division's wind converter and the Borderline 1000 traction converter. At this time, both the ACS 6000 and Borderline 1000 product families represent significant production volumes for the Turgi site.

The Splügen project is a venture between two ABB country organizations, ABB Switzerland and ABB Poland. ABB Poland is responsible for coordinating the real estate development and providing the shared services for the site. As the customer, ABB Switzerland is responsible for managing the product development and transition process and supporting the integration of the new venture's business processes with those of ABB Switzerland.

Historically, the Turgi Site has employed a craftsman-like job shop assembly strategy for most of its products. Within the past two years, operations leadership experimented with the introduction of flow production concepts on two highly standardized product lines with some success. As such, the operations leadership for the Splügen venture have developed a lean assembly vision for the Splügen facility which incorporates flow production and other lean concepts. Consequently, a significant change in the design of the supply chain must be undertaken to support this new vision. Today, the Turgi operations procure a significant portion of the components used in assembling most products are purchased on an order-by-order basis. Supplier delivery difficulties and challenges associated with project kitting at the company's third party logistics provider often result in parts shortages for critical components and delayed delivery or added cost. To address these issues, the Splügen supply chain seeks to switch procurement to a stock-based strategy for the majority of components. The development of the supply chain concept for the Splügen facility, the conversion of the supply base to stock-based delivery and the development of detailed inventory management parameters will be the focus of this thesis.

1.5 Three Lens Analysis

Project Splugen is a complicated venture that spans multiple country organizations and profit centers within ABB Switzerland. In addition to the internal stakeholders, suppliers, third party logistics providers, and countless other stakeholders are impacted by the venture. The three lens analytical framework "distills the essence of related theories that share ideas about human nature, the functions of organizations, the meaning of organizing, and the information needed to make sense of an organization."[3] The following analysis is meant to provide insight into the organization of the project team, the power structures at play and cultural challenges that exist.

1.5.1 The Strategic Design Lens

The project team for Splügen is organized by country business unit. As the Swiss business unit initiated the venture and is acting as the customer, ABB Switzerland is the leading business unit for the project. At the time of the internship, the Swiss business unit had 6 dedicated resources – A Project Leader and five functional leaders that are each responsible for a functional aspect of the project. The five functional aspects are supply chain, supplier management, quality and production engineering. The Polish support team slowly staffed dedicated resources during the course of the internship, eventually hiring a production engineer, production planner and production supervisor. ABB Poland is organized by function, with the directors and a few individual contributors supporting the project for the bulk of the project. The final element of the project structure is the steering committee which oversees the planning and execution of the venture. This committee is composed of senior executives from both the Swiss and Polish organizations.

The structure of the project team exhibits both the biases of the organizations and the vision for the long term organization of the venture. The concept behind the leadership of the development venture coming from ABB Switzerland is based on the fact that in order for the project to be successful, the business processes must be tightly integrated between the two country organizations and that the product expertise lies in Switzerland. The logic for the execution team being Polish is of course based on the fact that sustained operations will be run by them, and the detailed

[3] Carroll, J. S. (2006). Intorduction to Organizational Analysis - The Three Lenses. *MIT Sloan School of Management Working Paper*, 1-13.

configurations and systems should be developed in a way that is compatible with their existing processes and systems.

1.5.2 The Cultural Lens

The Splügen project is a significant cultural event for the Swiss organization. Splügen represents the first time that the particular business unit has moved the assembly of modules to a new low-cost location. This is significant because in making the move the Swiss are not only relocating work, which can be an emotional event, but they are also admitting that there are others that are capable of matching their assembly competencies, a serious acknowledgement given the history of and pride in Swiss craftsmanship.

The move also communicates a shift in strategy for ABB. It is an indication to the Swiss organization that ignoring assembly costs is no longer a feasible strategy and that the allocation of value creation will need to be reconsidered. A consequence of moving production to a low cost country is an increased demand for standardized products. Historically ABB has a strong engineering tradition and inherently – and often mistakenly – believes that most of its products should be engineered to order. As such, the efforts to make product modifications to support this venture and reduce the potential number of configurations for the models is a significant departure for the company.

Another critical cultural aspect of the project is clearly the fact that it spans two country organizations. The Polish and Swiss cultures are quite different, but to this point there have not been any significant cultural conflicts. At times, however, there have been instances where situations become tense due to frustrations stemming from communication in English between non-native speakers. A greater cultural barrier actually exists between the ABB country organizations. ABB Switzerland is a mature organization that does business around the world, whereas ABB Poland is a developing business that acts as a low cost country supplier or assembler for other ABB country organizations. For that reason, the interests and focuses of the two country organizations are often disparate.

1.5.3 The Political Lens

The interests of the groups working on the Splügen project are at once unified and disparate. All parties agree that the focus is to develop a world class manufacturing facility that builds quality products for ABB's customers. What is interesting, however, is the dispersion of ulterior goals and interests that rest beneath the surface.

This analysis will first address the interests at the business unit level. The business unit management for ABB Switzerland is the party that initiated the Splügen venture in hopes of eliminating a capacity shortage in their existing facility and realizing cost savings from low cost country sourcing and assembly. The business unit management is interested in developing the Splügen facility into a tightly integrated "extended workbench" that provides access to low cost components and labor. However, because the business unit management is evaluated on profitability they are not interested in developing ABB Poland's resources dedicated to Splügen into roles higher on the value chain, such as engineering or extensive purchasing and sourcing. In sharp contrast, however, ABB Poland's business unit management working on Splügen would like to increase ABB Poland's revenues and have identified offering services higher on the value chain, and controlling material purchasing as an ideal way of doing so. Given that ABB Poland is responsible for the investment in the facility it is completely rational for them to try to find ways of offsetting the costs that they have incurred.

From the perspective of power in the organization, ABB Switzerland clearly has more power in the relationship because they are the customer in the arrangement and ultimately control the product allocation for the venture. Interestingly though, because ABB Poland is making the investment in the real estate and facility development, this power is tempered by certain obligations on the part of ABB Switzerland to meet required revenue levels at the facility. To make it more interesting, the firm details of the arrangement were never written in a contract, as ultimately this relationship is one part of ABB doing business with another, so there were on-going negotiations throughout the duration of the project – clearly not helping the process along. Historically, relations have been amiable and decisions facilitated by the fact that the steering committee has representatives from both business units on it. However, it is easy to see the potential on the horizon for an upcoming power struggle.

At the functional level of the organization there are also some interests that overlap and sometimes create tension. As stated in the strategic section, the project is organized in such a way that the functional leadership for each aspect of the project reside in the Swiss team. However, the tactical responsibility and long term ownership of the processes will reside with the Polish team. This has created some interesting situations. For instance, ABB Poland is interested in creating operating policies for the facility that match those that they use in the rest of their facilities. However, in analyzing the supply chain, it has become clear that these practices are suboptimal and as such, a number of alternative recommendations for the facility have been made. While both parties are concerned about costs, ABB Switzerland is the organization that has to pay the expenses of the facility and as such is interested in optimizing the supply chain network. In contrast, ABB Poland is the organization that has to run the day to day operations of the supply chain and hence they are more interested in commonality across their entire organization – Note: another perverse incentive is that ABB Poland receives a small margin on all costs, so from a revenue perspective higher costs mean more money for them. In the end, most matters have been resolved but this tension has been visible throughout the process design of the facility.

2 Project Elements & Vision

This section of the document provides an overview of the supply chain mechanisms and concepts that were developed at the early stages of the internship. These attributes of the functioning supply chain provide the framework in which the inventory management aspects of the thesis must function. Specifically, the topics of order handling, production scheduling and the three phases of the procurement strategy will be covered at length.

2.1 Order Handling

The sales transactions for all modules produced by the Splügen facility will continue to be performed by the central staff of the Swiss business unit. As such, orders placed to the Splügen facility will essentially be production orders from the Swiss business unit.

Order Placement

Production orders from business units to the Splügen facility will include the following information in an electronic format:

- Module Configuration: After configuring the module to be ordered, the home unit will include this configuration in the order package.
- Configured Bill of Materials: The business unit organization will continue to perform the configuration process for modules to be assembled by ABB PL at the Splügen facility. As such, a Bill of Materials for each module including all required materials will be included in the order.
- Due Date: The business unit will also supply the date when the module must be delivered to Turgi by. This date will reflect the testing and final assembly schedules in Turgi as appropriate.

ABB PL Order Receipt

ABB PL will receive the order and confirm acceptance of the terms and the ability to meet the delivery timeline. Order data will be entered into the PL ABB SAP system by the order handler. After completion of the process, as detailed in Appendix 1, the ownership of the process will be transferred to the responsible production planner.

2.2 Production Scheduling

Due to the use of a flow production strategy and the fact that orders to Poland will logically be placed in order of due date by ABB CH, the production scheduling process for the Splügen assembly lines should be a simple process.

Upon receipt of a production order, the order will be placed into the appropriate line's production queue based on the order's required completion date. This position in the queue can then be directly tied to a start date and time on the assembly line (and consequently a completion date) based on the line's unique takt time and future operating schedule (ie. Overtime, scheduled downtime, etc.). To complete the production scheduling process, the Production Planner must confirm that the revised schedule does not cause any modules to miss their completion targets. If this is not the case, the production planner must receive approval to alter the delivery date or alter the future operating schedule to facilitate on time delivery.

By using this scheduling process, it will be guaranteed that the production of a certain module is never pulled forward, which would create the potential for a revised and earlier material readiness date for order based parts. Additionally, the scheduling process will give priority to orders with the earliest due dates, thus facilitating on time delivery.

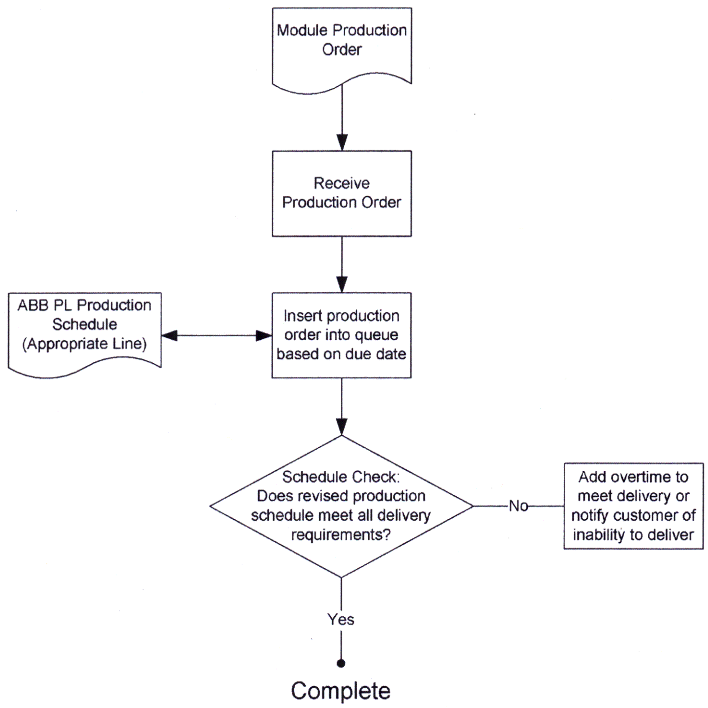


Figure 3: Module Production Scheduling Algorithm Overview

2.3 Material Procurement

The Splügen material procurement strategy will consist of two main categories of material, order based and stock-based, will be procured by the purchasing organizations of both ABB Poland and Switzerland, and will evolve through the course of three phases of implementation as is required by the readiness of the facility, SAP systems and ABB PL purchasing organization.

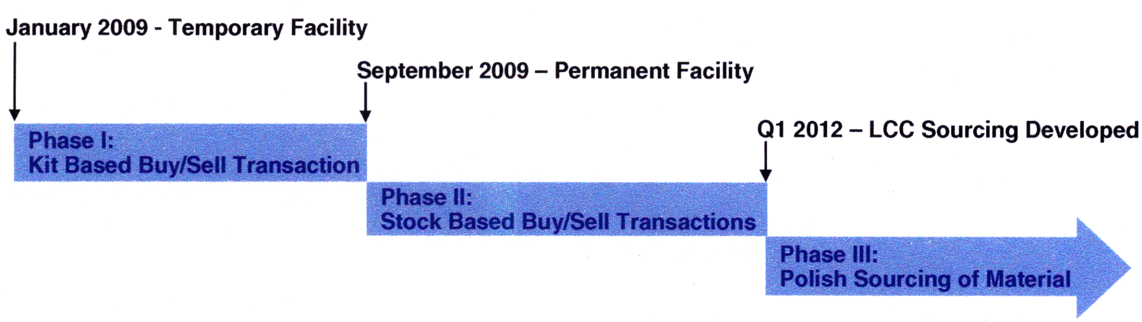


Figure 4: Fulfillment Strategy Phases and Timing

2.3.1 Procurement Strategy Phase Overview

The procurement strategy for Splügen consists of the following three developmental phases:

Phase I: Kit based buy/sell transactions: In the initial phase of Splügen activities, complete kits of the required components will be created at Rhenus's Spraitenbach facility and delivered to the temporary facility in Lodz. This phase of the project will last until the permanent facility is occupied in October, 2009. ABB Poland will be responsible for the sourcing of c-parts in Phase I. See Figure 5 for process details. Note that in this phase, component inventory that has not been kitted for assembly will reside in Switzerland at the Rhenus facility with the exception of fasteners and low level parts, which will be procured by ABB Poland.

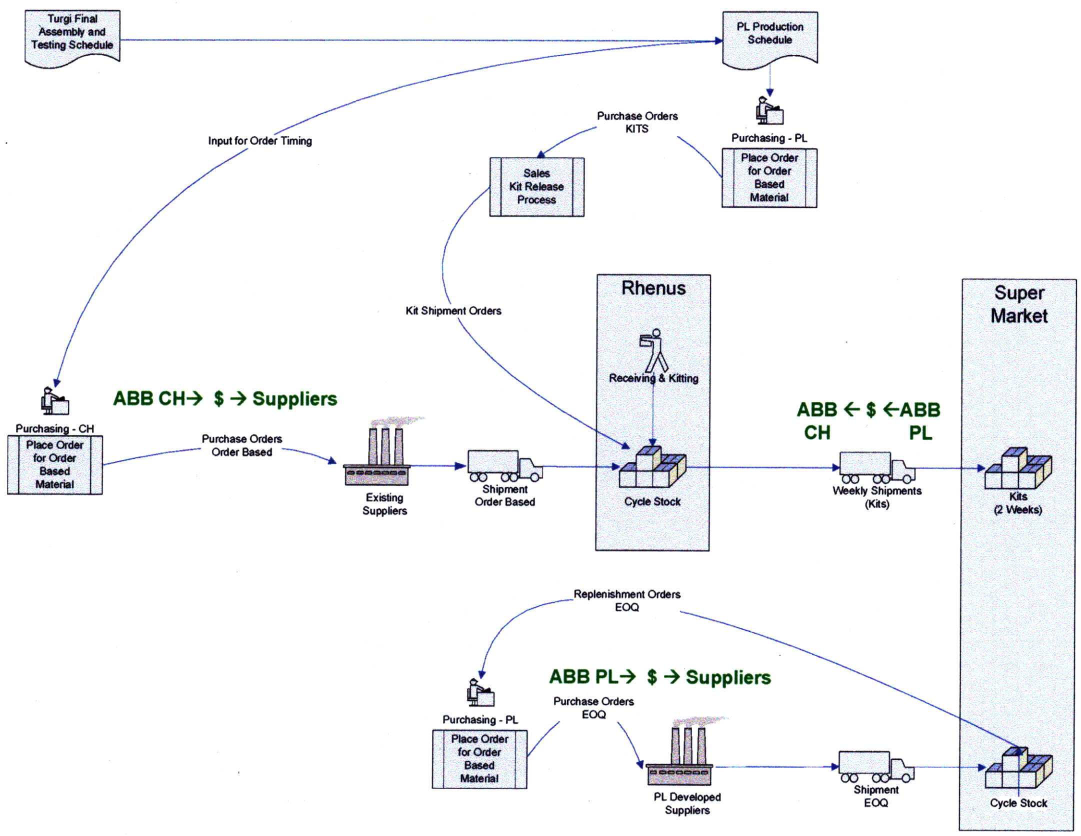


Figure 5: Temporary Facility Phase Process Detail

Phase II: Stock-based buy/sell transactions: Phase II of the procurement strategy will commence upon occupation of the permanent assembly facility. In this phase stock-based delivery will begin, with purchasing of components being completed by the organization which developed the supplier. Materials sourced by ABB CH will be purchased by ABB PL when transferred to the Polish warehouse. During this time, ABB PL will be focusing on developing and transitioning to low cost country suppliers and implementing inventory management principles in the Splügen warehouse, to manage the cycle stocks for the Splügen specific components now located in the Polish warehouse. In this Phase, ABB PL will also assume responsibility for purchasing order based components. Completion of this phase is targeted in early 2012. Note the additional complexity passed to the assembly facility and logistics providers as shown in Figure 6.

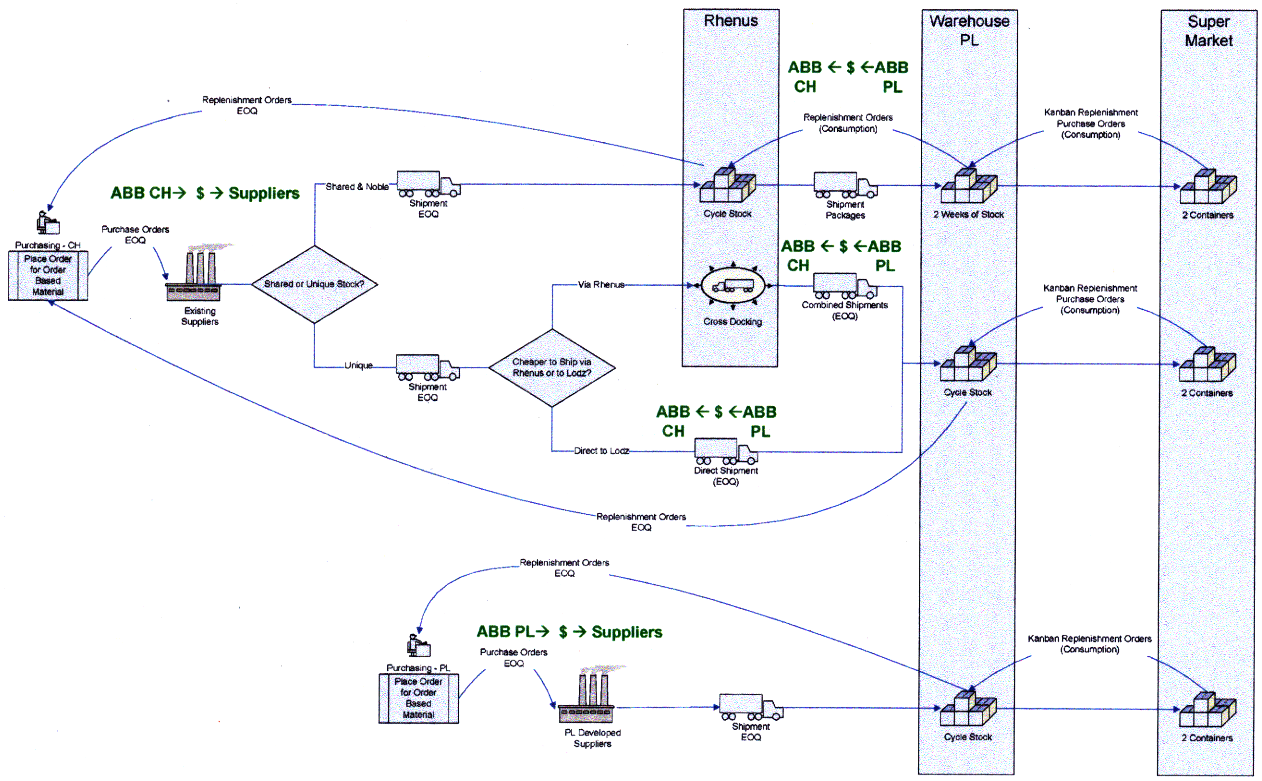


Figure 6: Phase II Process Detail

Phase III: Polish Sourcing of Materials: In early 2012, ABB PL will assume responsibility for the procurement of all components used in the assembly of modules at the Splügen facility. By this time, ABB PL's sourcing organization should have converted most components with LCC sourcing potential to new suppliers and will be in a position to inherit the purchasing responsibility for materials supplied by existing ABB CH suppliers.

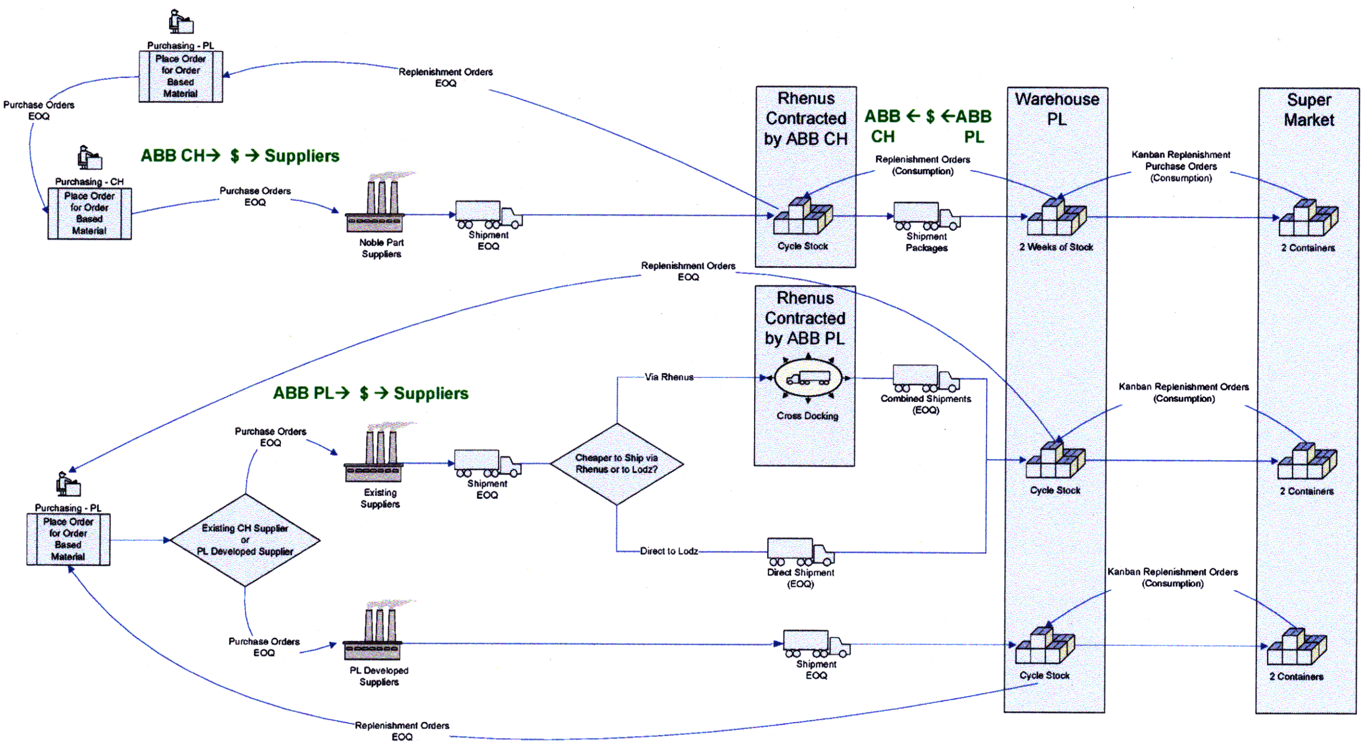


Figure 7: Vision Obtainment Process Detail

The rationale behind the phased procurement strategy is as follows:

- Information technology and supply base development requirements prevent the supply chain from being prepared for stock-based delivery in time for the start of operations in the temporary facility in January, 2009.

- The implementation of Phase II allows for ABB PL's purchasing and sourcing organizations to focus on developing low cost country suppliers for components, yielding valuable cost savings to the project, while still allowing for the optimization of the supply chain from a transportation and inventory management perspective.
- Phase III is the optimal long term procurement model, as it eliminates redundant purchasing transactions and allows for supply chain optimization. Delaying the implementation of this strategy reduces the risks of start-up activities and allows for the proper focus in the ABB PL supply chain organization.

2.3.1.1 *Phase II Business Model Alternatives Evaluation*

In order to decide on the optimal operating plan for the Low Cost Country Development Phase (Phase II) of the Splügen venture four variations of the operating plan were evaluated. The alternatives are detailed below:

Enrichment: A business model that would allow for duty and tax free import of materials into Poland for the purpose of adding value in a local facility and exporting enriched goods from the country.

Module Based Buy-Sell Transaction: Under this model ABB Switzerland would be responsible for purchasing and managing all materials that are not purchased in Poland. Under this model, ABB Poland would place replenishment orders to ABB Switzerland to allow for them to minimize working capital.

Service Based Transactions: ABB Switzerland would register for VAT purposes in Poland. ABB Poland would be responsible for LCC Sourcing and would be compensated for value added and materials sourced while ABB Switzerland would own inventory in both Switzerland and Poland.

Buy-Sell Procurement Strategy: Under this business Model, ABB Switzerland would remain responsible for purchasing materials and would transfer the inventory to ABB Poland through a sales transaction. ABB Switzerland would then repurchase those materials when receiving the final assembled module. Under this model two options existed for ABB Switzerland's VAT registration status in Poland, either to register or remain unregistered. In the end, due to VAT reclamation delays and risk in Poland, it was determined that it would be optimal for ABB Switzerland not to register for a VAT account in Poland.

It is important to note that within each of these contexts the fundamental amount of value added does not vary dramatically. However, the expenses in the form of VAT and Duty differ dramatically, which would have significant financial impacts on the venture's profitability.

2.3.1.2 *Evaluation Method*

In order to analyze the business model options for Phase II of the Splügen venture a model was constructed to evaluate the financial impact of each of the plans. This model incorporated the impacts that each operating plan would have on the following cost drivers:

- Transportation costs: How would the optimal behaviors in each of the scenarios affect shipping methods and routes? For instance, the enrichment business model would allow for direct shipment of goods to the Polish facility, where as the Buy-Sell Transaction model would require all Swiss purchased goods to pass through Switzerland, driving transportation costs up.

- Administrative Costs: What are the administrative costs associated with order placement and handling, customs clearance and other administrative aspects of the purchasing process?

- Duty and VAT payments: How would ABB Switzerland's registration status and the shipping methods employed impact the expenses and cash flows of the project ?

- Inventory levels: How would the ownership arrangements in each of the business models affect the inventory levels in each of the supply chains warehouses and assembly facilities? For instance, the inventory levels driven by the Module Based Buy-Sell Transaction model would locate all inventory in Switzerland with only cycle stock located in Poland and require multiple echelons of safety stock whereas the enrichment model would only require inventory in Poland where holding costs are significantly reduced.

2.3.1.3 *Phase II Business Model Recommendation*

Upon completion of the analysis it was determined that the Buy – Sell Procurement Strategy without VAT registration was the optimal business model to employ during Phase II of Project Splügen. The Rationale for this decision was as follows:

- Lower cost option
  - Elimination of administrative costs associated with tax and customs registration
  - Does not require VAT payments on warehousing services as ABB Poland's status as a net exporter allows for exemption within the EU customs regulations
  - Allows for optimization of supply chain since this business plan does not provide any dis-incentive to store inventory in Poland or pose any time limits storage times
- Lower complexity option
  - Reduces number of transactions and simplifies invoicing
  - Simplifies SAP implementation as additional modules are not required to perform transactions or manage inventory in a off-site location
  - Eliminates ABB CH VAT reclamation process because ABB Poland will operate on an export credit basis
  - Because ABB CH and ABB PL are net exporters in their respective countries, VAT will be handled on an account basis and never have to be paid
- Allows for the potential of implementing consignment warehouse in the future (potentially as early as 2009 – Polish regulations require prevent registered companies from entering into consignment model in the future)

While this business model was clearly the optimal framework for the operations there were some detrimental implications associated with it. First, because this model required ABB Poland to purchase all of the materials consumed in the assembly of goods at Splügen either directly or from ABB Switzerland, ABB Poland's working capital investment for the project would have to increase significantly from the original concept. Secondly, because ABB PL would be responsible for inventory management and initiating the purchasing process by ordering material from ABB Switzerland, it was possible that replenishment lead times could increase by as much as 3 business days, further increasing safety stock levels and working capital investment for ABB Poland and adding administrative complexity to the purchasing process.

2.3.2 Order Based Procurement

All procurement for order based materials will be transferred to the ABB PL purchasing organization upon the initiation of Phase II of the procurement strategy. Orders for materials in this procurement category will be placed 3 months prior to the scheduled start of production in Lodz. However, the goal of the project is to minimize the number of order based components allowing for a more simplified inventory management strategy.

2.3.3 Inbound Logistics & Customs Clearance

Transportation cost will play an important role in assigning commodities to one of the supply chain categories. Besides commodities that have been classified as order based or Polish sourced, all components will be evaluated for their optimal shipping path. This determination will be whether it is more cost effective to ship the material directly to Poland or to make use of the capacity of the weekly shuttle running from the Turgi to Lodz. One of the key constraints in this decision will be the capacity of the weekly shuttle. If capacity is reached, commodity transportation assignments will be prioritized based on savings potential.

2.3.3.1 *Direct Shipment*

Direct shipment will be the default shipping method for commodities that are only required at the Splügen facility. Commodities that are shipped directly to Poland will likely be high volume components that can fill truckloads with their economic order quantities or have suppliers that reside in a location equidistant from Poland and Switzerland.

2.3.3.2 *Indirect Shipment*

Indirect Shipment will be the shipping strategy employed for materials that fall into the shared commodities category or those commodities that are unique to Polish operations but have demand or supply characteristics that allow indirect shipment to be a more cost effective solution. If the demand or supply characteristics of the commodity lend themselves to an indirect shipping strategy, the cycle stock will be shipped to the Rhenus facility in Spreitenbach. Rather than storing this material, Rhenus will perform a cross docking service and load this material on the next available Splügen shuttle. By utilizing this strategy, the venture will be able to reduce transportation cost for many commodities supplied by Swiss suppliers, low volume suppliers or those that provide free shipping to Spreitenbach today.

2.3.3.3 *Shared Commodities*

Because shared commodities will have their cycle stock and safety stock located at the Rhenus facility, they will be shipped by their suppliers to Spreitenbach, Switzerland. As noted in the section 2.3.3 replenishment orders for the working stock at the Splügen facility will be replenished on a weekly basis via the Splügen shuttle.

3 Inventory Allocation and Management

3.1 Chapter Introduction

After defining the supply chain concept for the Splügen facility, the next phase of the project was to develop commodity-specific, supply chain category assignments for commodities and to develop the inventory management parameters that would govern the system. This chapter introduces the context of the problem and the derivation of the analytical frameworks used to develop solutions. Topics discussed at length include the development of economic order quantity parameters, the derivation of a continuous review inventory policy for establishing safety stock and reorder point levels and the implementation of the generalized power rule for demand variability forecasting. The final section of this chapter incorporates these concepts and describes the functionality of the Splügen supply chain analytical model that was created to tackle the inventory management challenge.

3.2 Problem Statement: Inventory Allocation and Management

The challenge of this stage of the project was to determine the optimal way to manage the procurement and shipment of components throughout the project's and business unit's supply chain network, which consisted of hundreds of suppliers, two warehouses and two assembly sites – one of each located in Poland and Switzerland. Within the supply chain context of the Splügen project determining the optimal supply chain configuration for each commodity boiled down to assigning each commodity to one of the four supply chain categories (See figure 8 for a simplified schematic) and for those assigned to stock-based categories determining the appropriate order quantities, reorder points and safety stock levels.

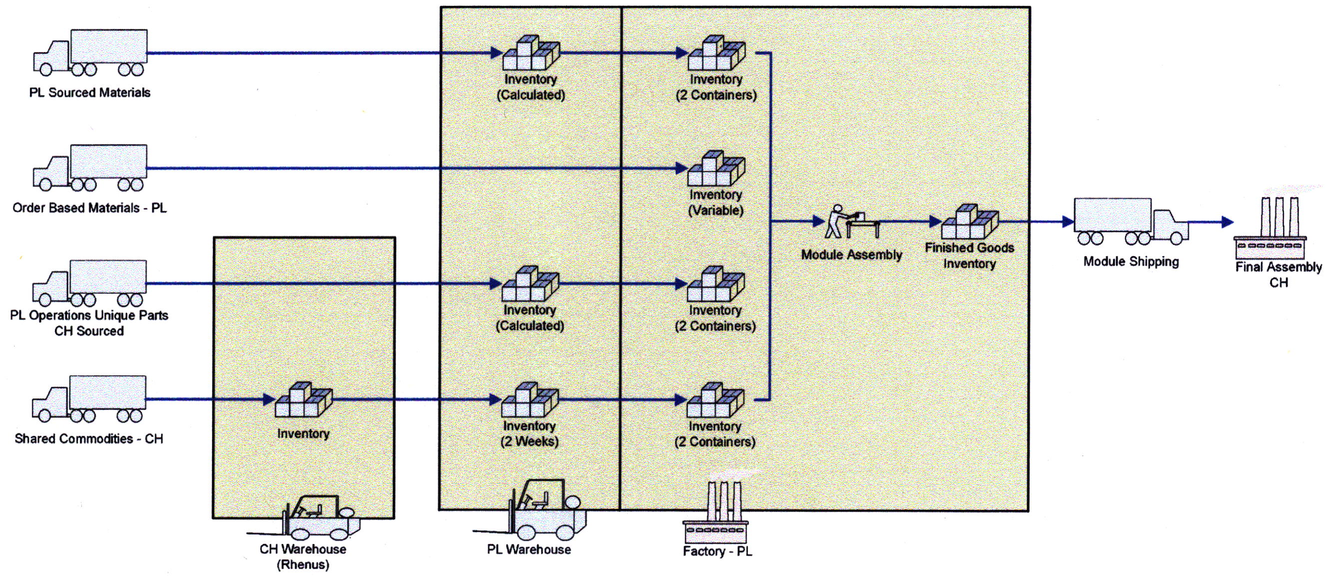
At its core this problem is straight forward and can be simplified into the three questions below:

- Locations of use: Is use only in Poland or is the commodity also used in Turgi?

- Volume of use: Is the volume of use sufficient to justify the use of a stock-based strategy or does it make more financial sense to procure the part on an order by order basis when it is needed?

- Transportation costs: Does it make economic sense to ship directly to Poland or is it more cost effective to use the cross docking service at the Swiss 3rd Party Logistics Provider and ship to Poland on the Splügen Shuttle?

However, to decisively answer the questions each component must be evaluated within each of the four supply chain categories to determine what the most cost effective solution would be.



Supply Chain Category	Purchasing Organization	Shipping Method	Inventory Location
Polish (PL) Sourced Materials	ABB Poland	Direct from Supplier	Polish Warehouse
Order Based Materials - PL	ABB Poland	Direct from Supplier	Polish Factory
PL Operations Unique Parts – CH Sourced	ABB Switzerland	Direct from Supplier or Via Swiss 3rd Party Logistics Provider	Polish Warehouse
Shared Commodities - CH	ABB Switzerland	Via Swiss 3rd Party Logistics Provider	3rd Party Logistics Provider

Figure 8: Splügen Supply Chain Categories and Schematic. Note that inventory quantity descriptions are defined as follows. Calculated indicates that inventory levels are managed in accordance with an order-point, order-quantity management strategy and that parameters are calculated based on these principles. Variable inventory indicates that stock levels are uncertain as this part category is only ordered when low volume configurations of products are in the future production schedule. Also note that the targeted inventory level for shared commodities in the Polish warehouse is two weeks due to replenishment cycles out of the Swiss third party logistics provider, Rhenus.

3.3 Approach

The primary initiative in the realm of inventory management is the result of the modification of procurement from an order-by-order basis to a stock-based strategy. By using this stock-based strategy, the requirements of the purchasing process will be significantly reduced, material readiness for build will improve and spending on procurement and storage will be optimized.

In order to understand and analyze the commodities against the four alternative supply chain models, it was necessary to engage the existing supply base to modify order quantities, packaging methods and obtain quotes for the shipping alternatives. By working with the Supply Management Group from ABB's Medium Voltage Drives and Power Electronics Business Unit, all suppliers for the lead product unit were asked to complete a packaging and shipping proposal. This proposal, as seen in Appendix 1, requested a proposal for stock-based delivery including quantity of goods per container, order cost modifications, and a quote for the expected expense associated with shipping commodities to both Poland and Switzerland . To facilitate the proposal process, a series of guidelines were provided as seen in Appendix 2. Within these guidelines suggestions for standard containerization and estimated order quantities were included in hopes of improving the quality of supplier responses.

Once the proposal information had been received, it would then be theoretically possible to analyze the inputs in a model and determine which of the four supply chain categories provided the most cost effective means of procuring and storing the individual commodity. This analysis would use commonly accepted frameworks such as economic order quantity and safety stock models to determine the optimal inventory management parameters and the associated costs for each commodity. More detail on these models can be found in section 3.3.1 below.

Upon completion of the analysis it would then be possible to re-engage the components suppliers to iteratively improve their proposals either through the modification of order quantities or packaging methods to arrive at an improved solution set.

3.3.1 Inventory Management Strategy Overview

Stock-based inventory in the Splügen supply chain will pass through one of four possible chains including various combinations of the Rhenus Spraitenbach warehouse, the ABB PL warehouse and the Splügen supermarket. Cycle Stock and Safety stock will be optimally located in either of the warehouses and all material delivered to the production floor will pass through the supermarket. Overall supply chain costs for the Splügen venture will be minimized through the use of an Economic Order Quantity (EOQ) and Safety Stock strategy which balances order cost, transportation cost, and holding costs for a given service level at the Splügen facility. The current targeted service level for the supply chain is 95%.

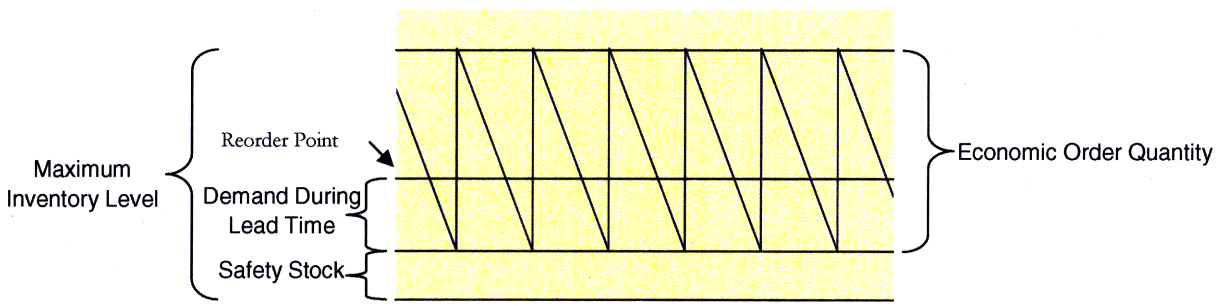


Figure 9: Economic Order Quantity Inventory Model

3.3.2 Economic Order Quantity

The economic order quantity model or economic lot size model in its classic form provides a framework for balancing the tradeoffs between ordering and storage costs for a single commodity. Because of its simplifying assumptions, such as no demand variability, it will serve as a starting point for this analysis. In order to derive the optimal order quantity for a good, the economic order quantity model assumes the following:

- Demand is constant at rate D items per period
- Order quantities are constant. Namely every time the warehouse places an order to a supplier it orders Q items

- A fixed cost of K is corresponding to a setup cost is incurred for each order placed by the warehouse
- A holding cost of h is incurred for every unit in inventory per time period
- The lead time between the placement of an order and its receipt is zero
- The planning horizon is infinite

From these assumptions it can easily be inferred that the average total cost of the system per period is

$$\frac{KD}{Q} + \frac{hQ}{2}$$

Where $\frac{KD}{Q}$ represents the average order cost of the system per period and $\frac{hQ}{2}$ represents the average holding cost of the system per period. By simplifying this expression and taking the derivative with respect to Q it can easily be seen that the optimal order quantity Q* is

$$Q^* = \sqrt{\frac{2KD}{h}}$$

While this framework is simple it does provide insights into the optimal ordering quantities and can be modified to include other parameters. [4] In the context of the Splügen project shipping costs and inventory holding costs are significant factors in the deciding between shipping methods. For that reason the definition of K was extended beyond the order set up cost in the traditional model. In the Splügen model K is defined as the total order and shipping costs incurred each time an order is placed by the warehouse.

The assumptions utilized in the Economic Order Quantity model also pose some problems. To begin, the products being assembled by the Splügen venture do not have a constant demand rate and can be configured in thousands of ways. Using a model that assumes constant demand for a

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[4] (2003). In P. K.-L. David Simchi-Levi, *Designing & Managing the Supply Chain: Concepts, Strategies & Case Studies. Second Edition* (pp. 47-48). New Delhi: Tata McGraw-Hill Pulishing Company Limited.

commodity is not accurate. Additionally, the model implicitly assumes that there is no demand variability between the placement of the order and receipt of the goods. Again this assumption is unreasonable. For that reason it becomes necessary to employ inventory review policies, demand forecasting and safety stocks to account for the variability and risk in the system.

3.3.3 Continuous Review Order-Point, Order-Quantity Inventory Policy

To account for the short comings in the economic order quantity model it is possible to employ a continuous review policy. A continuous review policy, as defined by Simchi-Levi, Kaminsky & Simchi-Levi, is an inventory policy "in which inventory is reviewed every day and a decision is made about whether and how much to order." The policy specifies an order level, *s*, and an order quantity *Q**. The decision regarding whether to place an order or not is based on the current inventory level in the warehouse and its position relative to a prescribed reorder level *s*. Implementing a such a policy is a feasible and realistic option given the IT system capabilities of ABB's Medium Voltage Drive & Power Electronics Business Unit and those planned for Splügen by ABB Poland's IT organization.

To employ a continuous review policy, the following assumptions must be made [5]:

- Daily demand is random and follows a normal distribution
- A fixed cost K is incurred every time an order for a commodity is placed.
- A unit holding cost h is incurred for every unit held each time period it is in inventory
- The inventory level is reviewed at the end of every day
- If an order is placed the order arrives after the prescribed lead time L
- Orders that arrive during a stock out are assumed to be lost
- The ordering organization specifies the appropriate service level for their business climate[6].

A continuous review inventory policy defines two values for each commodity considered, an order-point and an order quantity. First, it defines the order level *s*. Also known as the order point, *s*,

[5] (2003). In P. K.-L. David Simchi-Levi, *Designing & Managing the Supply Chain: Concepts, Strategies & Case Studies. Second Edition* (pp. 58-62). New Delhi: Tata McGraw-Hill Pulishing Company Limited.

[6] Simchi Levi, Kaminsky & Simchi-Levi define service level as "the probability of not stocking out during lead time."

represents the inventory level that will trigger the warehouse to place a replenishment order for goods. Secondly, a continuous review policy, like the economic order quantity model, also defines the optimal order quantity represented as Q^*. The following sections of this text will provide an overview on the definition of these two parameters.

3.3.3.1 *The Reorder Point*

To define the reorder point within the context of a continuous review inventory policy the following information is required:

- D_A = The average demand for the commodity during a time period
- σ_A = The standard deviation of demand during a time period
- L = The lead time for replenishment of commodities from the supplier to the warehouse expressed in time periods
- α = The desired service level of the firm employing the policy, where 1-α is equal to the probability of a stock out

Using these parameters it is now possible to define the two components of the reorder level *s*. The first component of the reorder level is the demand during lead time. In order to cover the demand during lead time it is fairly intuitive that this quantity can be calculated by multiplying the average demand for a period of time by the lead time for replenishment. This quantity can be represented algebraically as:

$$D_A \times L$$

The second component of the reorder point is the safety stock which is meant to account for the variability of average demand during the replenishment lead time. This quantity can be represented as :

$$z \times \sigma_A \times \sqrt{L}$$

Where z is a constant equal to the inverse normal distribution of 1-α. Therefore, it can be concluded that the reorder level is equal to the sum of the average demand during lead time and safety stock level corresponding to the service level α. Expressed algebraically the reorder point is:

$$D_A \times L + z \times \sigma_A \times \sqrt{L}$$

3.3.3.2 *The Order Quantity*

Applying the same assumptions as stated in the overview of the continuous review inventory policy it is also possible to calculate the order quantity. By utilizing the economic order quantity framework, relaxing the assumption that demand is constant and instead utilizing average demand it can be seen that a close approximation of the optimal order quantity would be:

$$Q = \sqrt{\frac{2KD_A}{h}}$$

where h represents the holding cost per unit per time period of goods on stock.

3.3.3.3 *Conclusions and Validity of the Continuous Review Inventory Policy*

From the discussions above, a number of conclusions can be drawn about the performance characteristics of the continuous review inventory policy. They are as follows:

- The maximum expected inventory is equal to the safety stock level plus the order quantity or $Q + s$
- The expected inventory level at the time of order receipt is equal to the safety stock level which is:

$$z \times \sigma_A \times \sqrt{L}$$

- The average inventory level is equal to the safety stock level plus half of the order quantity expressed algebraically this is equal to:

$$\frac{Q}{2} + z \times \sigma_A \times \sqrt{L}$$

However, while the continuous review inventory policy provides an approximation of the performance of the Splügen supply chain two challenges still remain. The first challenge is tied to the assumption regarding lead time. While the continuous review inventory policy model does account for variability in demand rates, like the economic order quantity model, it still does not account for variation in replenishment lead times. To be an accurate and valuable model for the Splügen project, the inventory model must account for variability in the lead time as well as demand. Section 3.3.3.4 will address this challenge.

The second challenge associated with implementing the continuous review model, and any other model for that matter, is tied to accurately forecasting average demand rates and variability. Accessing data for historical demand patterns of commodities used within the Splügen supply chain is a feasible task. However, utilizing that data to accurately forecast future demand rates and variability poses yet another challenge. Section 3.4 of this thesis will discuss the approach used.

3.3.3.4 *Accounting for Variable Lead Times in the Continuous Review Inventory Policy Model*

As mentioned previously, one of the challenges associated with applying the continuous review inventory policy model to the Splügen supply chain is with the assumption that the replenishment lead times are assumed to be constant values with no uncertainty. While ABB and every other manufacturing firm in the world would find such a situation ideal, it is unfortunately not realistic. For that reason, modifications to the continuous review model must be made.

Recall from section 3.3.3.1 that the reorder point for the continuous review inventory policy is

$$D_A \times L + z \times \sigma_A \times \sqrt{L}$$

and from section 3.3.3.2 that the order quantity is

$$Q = \sqrt{\frac{2KD_A}{h}}$$

where

L = The lead time for replenishment of commodities from the supplier to the warehouse expressed in time periods and is assumed to be constant

Upon review of these formulas it become clear that the replenishment lead time variable only affects the value for the reorder point, *s*. For this reason, it is unnecessary to modify the order quantity within the model.

By introducing the following variables, it will be possible to modify the two components of the reorder point, *s*, to account for variability in lead time. Therefore let

L_A = The average lead time for replenishment of commodities from the supplier to the warehouse expressed in time periods

σ_L = The standard deviation of replenishment lead time

Using these variables it becomes possible to modify the two components of the reorder point to account for variability in lead time. First recall that demand during lead time in the original model is equal to

$$D_A \times L$$

With this in mind it is easy to conclude that average demand during lead time under a model that accounts for variability in lead time would be equal to

$$D_A \times L_A$$

as long as demand and lead time are not correlated. The second component of the reorder point by definition is safety stock. From the properties of conditional expectations it can be concluded that the standard deviation of demand during lead time is equal to

$$\sqrt{L_A \times \sigma_A^2 + D_A^2 \times \sigma_L^2}$$

And therefore that safety stock in the system, based on a normal distribution, should be equal to

$$z \times \sqrt{L_A \times \sigma_A^2 + D_A^2 \times \sigma_L^2}$$

where z is equal to the inverse normal distribution of $1 - \alpha$[7]. And therefore, the reorder point, s, for the continuous inventory review policy

$$s = D_A \times L_A + z \times \sqrt{L_A \times \sigma_A^2 + D_A^2 \times \sigma_L^2}$$

3.4 Demand Forecasting

Implementation of the continuous review inventory policy for commodities used in assembly for the Splügen project, as derived in the previous sections, requires accurate forecasts of both future demand rates for a period and future standard deviation of demand. According to Chopra and Meindl[8], there are four types of forecasting methods typically used in supply chain planning. They are as follows:

- **Qualitative forecasting methods:** These methods are subjective and rely on the judgment of experts within the firm or industry. Qualitative methods are appropriate for forecasting demand several years into the future and when little historical data is available.
- **Time series forecasting methods:** Time series forecasting methods assume that the operating environment is relatively stable and that past demand data is a good indication of future demand patterns.
- **Causal forecasting:** Causal forecasts assume that future demand is highly correlated with certain factors in the operating environment and use estimates of future conditions in the market to predict future demand.
- **Simulation forecasting methods:** Simulation forecasting methods combine causal and time series methods to determine how changes in the operating environment will affect future demand.

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[7] Meindl, S. C. (2001). *Supply Chain Management: Strategy, Planning, and Operation.* Upper Saddle, New Jersey: Prentice-Hall, Inc.

[8] Chopra, Meindl (2001). *Supply Chain Management: Strategy, Planning, and Operation.* Upper Saddle, New Jersey: Prentice-Hall, Inc.

Because of the timeline of the Splügen project, the forecasts for the system launch scheduled for 2010 were being made in mid 2008 in a radically changing environment due to the economic crisis. For that reason, the qualitative method of cumulative demand and configuration characteristics was the only alternative for forecasting at the module level. These forecasts were provided the company's best estimates for annual drive and module demand, but they did not provide the level of insight necessary to plan the inventory management parameters at a commodity level that were necessary for the implementation of the continuous review inventory policy envisioned for the Splügen project. Specifically, they did not provide any estimates for the standard deviation of demand. Another layer of analysis was necessary to determine the values for average demand rate and standard deviation of demand that would be employed in the model.

3.4.1 The Generalized Power Rule

Donald B. Rosenfield[9,10], introduced the concept of the power law, in the demand forecasting chapter of The Logistics Handbook to describe the relationship between demand and standard deviation. In this model, Rosenfield suggests that in general the standard deviation of demand is equal to the square root of forecasted demand. While this rule applies in general, Rosenfield expands the concept to the generalized power rule which states that the actual relationship between demand and standard deviation can be characterized as:

$$\sigma_A = \alpha D_A^{\beta}$$

where

σ_A = forecasted standard deviation of demand associated with a demand level D_A

D_A = forecasted average demand for the planning time period

α , β = parameters of relationship

[9] Rosenfield, D. B. (1994). Demand Forecasting. In J. F. Robeson, W. C. Copacino, & E. R. Howe, *The Logistics Handbook* (pp. 327 - 351). New York: The Free Press.

[10] Magee, J. F., Copacino, W. C., & Rosenfield, D. B. (1985). *Modern Logistics Management: Integrating Marketing, Manufacturing and Physical Distribution.* Wiley.

Therefore the generalized power rule implies that there is a linear relationship between the logarithms of demand and standard deviation which can be expressed as

$$\log \sigma_A = \beta \log D_A + \alpha$$

Given this relationship it is then possible to obtain the relationship parameters, α and β, by performing a simple linear regression on the logarithmic transformations of corresponding historic demand and standard deviation figures for the same planning periods.

3.4.2 Implementation of Demand Forecasting

In order to find a commodity specific forecast of future demand and variability using the generalized power rule two major steps must be taken. First, the relationship between demand and standard deviation must be ascertained from historical data. Secondly, a forecasted future demand must be entered into the expression to forecast the future standard deviation of demand.

3.4.2.1 *Fitting the Generalized Power Rule*

In order to understand the relationship between demand and standard deviation of demand historical data was gathered for the ACS 6000 module being studied. In order to provide a representative sample, 65 pairs of demand and standard deviation data were pulled from the MRP system. This data represented the past year's demand for individual commodities and included commodities from most potential configuration categories. See Figure 11 for sample raw demand data.

St	StlVerw	Werk	Obj	Komponentennummer	Alt	Pos.	EMOv	Einsat	ME	RMOv	Ergebnismenge	BME	Objektkurztext	Angel.am
1	1	0004	@9Z@	0011014544 002401		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/16/2001
1	1	0004	@9Z@	0011014544 002502		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/16/2001
1	1	0004	@9Z@	0011014544 002701		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/16/2001
1	1	0004	@9Z@	0011014544 002801		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/16/2001
1	1	0004	@9Z@	0011015349 001270		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/17/2001
1	1	0004	@9Z@	0011015349 001410		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/17/2001
1	1	0004	@9Z@	0011015349 001420		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/17/2001
1	1	0004	@9Z@	0011015405 001301		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/25/2001
1	1	0004	@9Z@	0011015405 002301		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/25/2001
1	1	0004	@9Z@	0011015405 003301		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/25/2001
1	1	0004	@9Z@	0011015405 004301		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	7/25/2001
1	1	0004	@9Z@	0011015657 001301		7305		6	ST		1.000	ST	EMC Filter INU	10/22/2001
1	1	0004	@9Z@	0011015657 001301		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	10/22/2001
1	1	0004	@9Z@	0011016202 001241		7305		6	ST		1.000	ST	EMC Filter ARU	10/23/2001
1	1	0004	@9Z@	0011016202 001241		7305		12	ST		1.000	ST	ACS6000 Max-Stückliste ARU-INU konfig.	10/23/2001
1	1	0004	@9Z@	0011016202 001242		7305		6	ST		1.000	ST	EMC Filter ARU	10/23/2001

Figure 10: Sample Raw Demand Data from MRP System

Upon completion of the data gathering, a linear regression was completed on the logarithmic transformations of demand and standard deviation of demand pairs to determine the general power relationship between the two key parameters. This regression yielded a line with the slope of 0.704 and intercept of 1.45. See figure 12 for the best fit line.

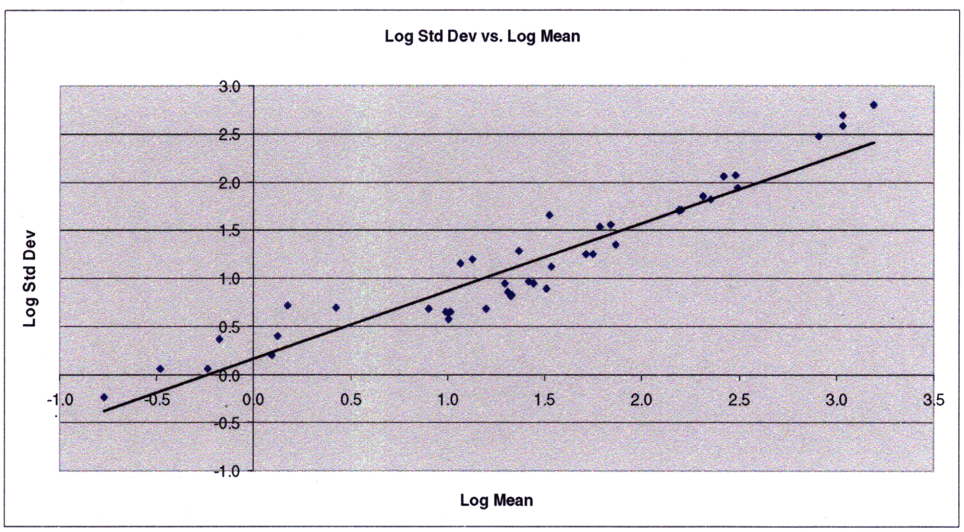

Figure 11: Logarithmic Transformation of Mean Demand and Standard Deviation of Demand

Given the slope and intercept of the best fit line it was then possible to algebraically express the relationship between average demand and standard deviation of demand as

$$\log \sigma = .704 \log \mu + .1613$$

which can be simplified to

$$\sigma = 10^{.1613} \mu^{0.704} = 1.45 \mu^{0.704}$$

Interestingly enough, the results of this analysis fit very closely with the empirical evidence provided by Rosenfield in The Logistics Handbook, which stated that most relationships are approximated by a value of .70 for β[11]. While theoretically one might expect a value of .50 if demand increments are independent, a higher β value, such as the one derived here, reflects some dependence.

3.4.2.2 *Forecasting Future Standard Deviation using the Generalized Power Rule*

With the generalized power rule derived from historical data, it is possible to forecast the standard deviation of demand associated with a given level of forecasted demand. For the Splugen project, it was decided that qualitative methods would be used to forecast future demand and configuration penetrations. This meant that a forecasts for future demand would be based on the following inputs

- A business unit forecast for 2010 demand for each module
- Component specific historic use data to determine the configuration characteristics of the commodity

This relationship can be expressed as follows

Future Forecasted Demand = Module Forecast x Historic Penetration in Modules

For instance, consider a part with the following historic demand characteristics

Average Monthly Historical Demand D_A = 32.5 units

[11] Rosenfield, D. B. (1994). Demand Forecasting. In J. F. Robeson, W. C. Copacino, & E. R. Howe, *The Logistics Handbook* (pp. 327 - 351). New York: The Free Press.

Standard Deviation of Monthly Demand $\sigma_A = 7.77$

Demand Reduction Factor (Business Unit Forecast) = 67.4%

Using this procedure, it would be possible to forecast future demand as

$$D_f = D_A \times 67.4\% = 21.9 \text{ units}$$

and future standard deviation as

$$\sigma_f = 1.45D_f^{0.704} = 1.45 \times 21.9^{0.704} = 12.73$$

3.4.2.3 *Mitigating forecast error in standard deviation*

It is commonly known that all forecasts are incorrect[12] and based on the use of qualitative methods and the uncertain nature of the business environment it would be unreasonable to expect the Splügen forecasts to be any different. Upon review examples of clear errors that could easily be corrected were observed and a methodology was developed to eliminate blatant over-estimates of future demand variability by relying on historic data.

To begin the discussion, consider a commodity with the following demand characteristics

- Historical average monthly demand D_A
- Historical standard deviation σ_A
- Forecasted future average monthly demand $D_f = .674D_A$
- Forecasted future standard deviation of σ_f

It is commonly agreed that when demand for a good decreases, that relative variability, often measured by the coefficient of variation, ρ, expressed as

$$\rho = \frac{\sigma}{\mu}$$

[12] Meindl, S. C. (2001). *Supply Chain Management: Strategy, Planning, and Operation.* Upper Saddle, New Jersey: Prentice-Hall, Inc.

will increase. Additionally, it is expected that without significant alteration to the structure of demand patterns, that standard deviation in absolute terms will decrease or remain the same. These two assumptions can be expressed mathematically as

$$\rho_f \geq \rho_A$$

and

$$\sigma_f \leq \sigma_A$$

where

ρ_f = the coefficient of variation of forecasted demand

ρ_A = the coefficient of variation of historical demand

σ_f = the standard deviation of forecasted demand

σ_A = the standard deviation of historical demand

In the case of the Splügen model, where forecasted future demand equated to a 22.6% reduction in historical demand one would therefore expect these same relationships to hold. However, upon reviewing the results of the general power rule forecasts, it quickly became evident that this was not the case. To mitigate this forecasting error, a rule was applied to all Splügen forecasts, which stated that the forecasted standard deviation of demand would be the lesser of the standard deviation of historical demand and general power rule forecast of standard deviation of forecasted demand or

$$\sigma_f = min\{\sigma_A | 1.45D_f^{0.704}\}$$

As the forecasted standard deviation is a substantial driver of safety stock and hence inventory, it is important that this correction is made so as to not over inflate the inventory that was being held by the Splügen project.

3.5 The Splügen Decision Model

To effectively and efficiently address the inventory allocation and management problem faced for affected components a model was built in Microsoft Excel. This choice allowed for simple data entry from ABB's MRP system, a highly adaptable user interface for data entry from supplier responses and the necessary level of calculation strength to address the problem at hand.

The model utilizes the supply chain concepts outlined in sections 3.3 and 3.4 to support supply chain analysts in determining the optimal supply chain strategy for an individual commodity. The key features and functionality of the model are detailed below:

- *Calculates historical demand parameters from raw MRP data:* Component specific data may be imported to the model simply using cut and paste functionality. From this data, the model filters the raw data to provide site specific data for historical monthly demand and standard deviation of demand.
- *Categorizes components based on historical demand data:* The model analyzes demand patterns to classify the components as either a shared or Splügen specific commodity.
- *Forecasts Future Demand:* Dedicated fields for both qualitative and causal forecasting allow for forecasting of the future demand and standard deviation of demand parameters. This functionality employs the generalized power rule and final product demand forecasts as discussed in section 4.4 of this thesis.
- *Calculates EOQ, Safety Stock & Reorder Point Parameters for all supply chain paths:* Using supplier provided packaging and shipping data, the model computes the key inventory management parameters for each of the potential supply chain paths, including direct shipment and cross docking.
- *Evaluates total cost of supply chain alternatives and recommends the most cost effective network solution:* By incorporating order costs, shipping costs and holding costs for each potential supply chain path, the model provides users with a recommendation for the most cost effective supply chain alternative.
- *Allows for sensitivity analysis:* The straightforward Excel template allows users to modify key inputs such as package size or lead time to gain insight into the major cost drivers of the commodities operating expense, allowing analysts to work with suppliers to develop more cost effective recommendations that are mutually beneficial.
- *Delivers one page summary of results to be shared with stakeholders:* The output of the model is a one page report summarizing the key parameters and costs of each of the scenarios. Similar

reports can be prepared detailing the system performance upon completion of sensitivity analysis to drive improvement through collaboration with suppliers.

Status: 0 **PRELIMINARY**

Part Number: 3BHL000720P0221 **Description:** Isolator GM221

Basic Data

Unique to Part				**Standard Data**	Mean	Std Dev
Container Size	50	Parts/SqM	1200	Lead Time		
Order Increment Requirement	24	Price	4.11 CHF	Spreitenbach to Poland	0.3125	0.129301
Min Number of Increment	1	Order Cost	0 CHF	Spreitenbach to Turgi	0.05	0.01
Min Order	1200	Shipping - PL	500 CHF			
Order Lead Time (Work Days)	2	Shipping - CH	100 CHF	*Exchange Rate = 1.5 EUR / CHF		
LT (Months)	0.1	Order LT Var	0.02			

Forecasting - PL Specific Use

Current Module Annual Demand	334	Variability Forecasting Slope	0.70451
Forecasted Annual Demand	225	Variability Forecasting Intercept	0.1636
Demand Scaling Factor	67.4%	Forecasted Variability	19.89929
Forecasted Demand - CBU Only	40.87	Variability for Calculation	19.90

Module Use Summary	
CBU	728
VLU/RBU	0
BCU	0
COU/TUE	0

	Pieces	CHF
Current Inventory	0	0
SAP Safety Stock Level	0	0
Minimum Order requirement	0	0

Demand Information - Individual Parts

	Poland	Turgi		Total
102007Poland	76	196	102007Turgi	272
112007Poland	28	209	112007Turgi	237
122007Poland	72	38	122007Turgi	110
12008Poland	68	152	12008Turgi	220
22008Poland	72	323	22008Turgi	395
32008Poland	44	228	32008Turgi	272
42008Poland	64	326	42008Turgi	390
52008Poland	40	95	52008Turgi	135
62008Poland	92	380	62008Turgi	472
72008Poland	92	304	72008Turgi	396
82008Poland	56	133	82008Turgi	189
92008Poland	24	57	92008Turgi	81
				Total
Mean	60.67	203.42		264.08
StdDev	22.68	112.60		114.86
	23.0%	77.0%		

Demand Information - Containers | Pkg size 50

Poland	Containers	Turgi	Containers	Total
76	1	196	3	272
104	1	405	5	509
176	1	443	0	619
244	1	595	3	839
316	2	918	7	1234
360	1	1146	4	1506
424	1	1472	7	1896
464	1	1567	2	2031
556	2	1947	7	2503
648	1	2251	7	2899
704	2	2384	2	3088
728	0	2441	1	3169
	Poland		Turgi	Total
Mean	1.17		4.00	5.17
StdDev	0.58		2.56	2.62

Inventory - Rhenus - Shared Model

	PCS	Containers	Pieces
EOQ	144.0	24	1200
ROP	86.8	2	100
Safety Stock	60.4	2	100

Inventory - PL Warehouse - Direct Model

	PCS	Containers	Pieces
EOQ	126.0	24	1200
ROP	33.9	1	50
Safety St.	19.5	1	50

Inventory - PL Warehouse - Shared Model

	PCS	Containers	Pieces
Safety Stock	50.0	1	50

Inventory - PL Warehouse - Via Rhenus

	PCS	Containers	Pieces
EOQ	56.3	24	1200
ROP	41.2	1	50
Safety St.	22.8	1	50

Inventory - PL Supermarket

	Average	Containers	Pieces
Supermarket	75.0	1.5	75

Cost Comparison - Shipping Methods

	Direct	Via Rhenus
Inventory - Units	650.00	650.00
Holding Cost	87.00	87.00
Cost of Capital	400.73	400.73
Order Cost	0.00	0.00
Shipping Cost	204.34	40.87
Total Logistics Cost	692.07	528.59

Recommendation: **Shared Model**

	Shared	Direct	Via Rhenus
PL Inventory Turns	3.92	0.75	0.75

Figure 12: The Splügen Supply Chain Model Output

4 Case Studies and Findings

4.1 Chapter Introduction

This chapter provides the results of a case study completed using the model and summarizes the general findings and conclusions gained through the application of the analysis method outlined in earlier chapters. The first case study discusses the topic of stock-based conversion and draws generalized conclusions about the potential cost savings available through the deployment of the continuous review inventory policy. The second case study evaluates a currently stock-based component, the resistor housing, to demonstrate the potential savings over existing inventory management practices employed by the company. Finally, a discussion of the model's sensitivity to different parameters is used to develop strategies that can be employed on Greenfield projects to generate savings or minimize additional costs within the operations of the supply chain.

4.2 Case Study Stock-based Conversion

Upon completion of development, the model was deployed. Working with a data analyst, the author of this thesis used the model to analyze the high priority commodities, namely those commodities used to assemble the Capacitor Bank Unit that were procured on an order-by-order basis at the time of the study.

Under this trial of the model 23 components were analyzed. Based on this analysis, it was concluded that 16 components were candidates for stock-based procurement. High level metrics used to determine feasibility of stock-based included forecasted inventory turns under the proposed inventory management parameters and the evaluation of historic and future demand forecasts.

A review of the results allowed for basic conclusions to be drawn about factors that contributed to performance metrics, which hindered the adoption of stock-based purchasing using a continuous review inventory policy. They were as follows:

- High Priced – Low Volume Commodities: Logically, high priced commodities with low volumes did not perform well under the continuous review inventory management parameters as their prices and relatively high variability drove holding cost expenses to exceed the savings achieved in order cost reduction. A prime example of this type of component was nickel plated copper bars, which were used in approximately 5% of configurations and cost significantly more than their non-plated counterparts.
- Commodities with Low Demand/High Variability: Figure 14 plots the forecasted coefficient of variation against average monthly demand. Clearly, as demand decreases for a commodity the coefficient of variation increases non-linearly driving the safety stock requirements for low volume/high variability commodities to drive holding costs high enough to once again offset order cost savings.

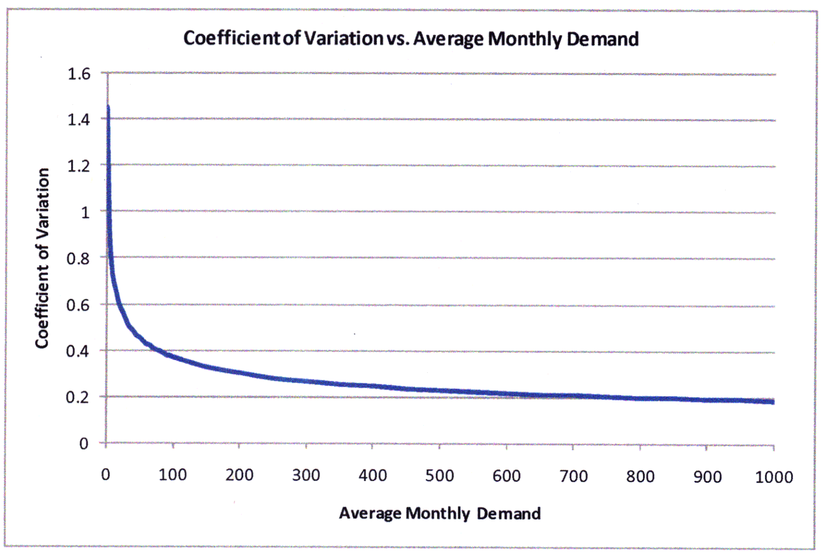

Figure 13: Forecasted Coefficient of Variation vs. Average Monthly Demand

Quantifying the improvement that the continuous review inventory policy would have over the current order based procurement strategy proved difficult. The primary reason for this was a lack of transparency at the 3rd party logistics provider caused by the incompatibility of information systems used by ABB and the provider. However, employing basic quantitative methods to a sample of the parts, it was found that this switch would reduce total operating costs attributed to the particular components by approximately 15 – 20% depending on volume.

4.3 Resistor Housing Case Study

As compared to the savings associated with the implementation of continuous review inventory management policies in the low volume realm of the commodities currently procured on an order-by–order basis, the savings found in high volume parts were much more dramatic. To provide an example of the benefits realized through the implementation of continuous review inventory policies combined with iterative improvement made possible by the model, a case study of one commodity's potential has been documented below.

The resistor housing is a simple, injection molded plastic part used across multiple products assembled at the Splügen project. As such, the part is stocked at multiple locations throughout the campus, and upon the launch of the Splügen facility, the part would also be stocked and consumed in Poland.

Preliminary review of the supplier proposal and ABB's MRP system revealed that the resistor housing was delivered in returnable rail containers containing 544 pieces per container with a minimum order requirement of two containers per order. At the time of review the average inventory level was calculated to be approximately 7,200 pieces totaling over 82,000CHF of inventory.

Upon reviewing the model results for the initial supplier proposal, it was found that merely implementing continuous review inventory policies to could reduce the inventory investment by 32% despite the addition of the Polish warehouse and supermarket storage locations. Further detailed review of the multi-location model revealed that opportunities for further improvement existed. The author and supply chain analyst both noted that the multiple user locations throughout the site coupled with large container size contributed to large quantities of work in process stock, which was not being consumed quickly.

Performance Characteristics	Current	Supplier Proposal	Splugen Proposal
Package Size	544 pcs	544 pcs	40 pcs x 24 boxes
Average Total Inventory	~ 7,200 pcs 83,000 CHF	~ 5000 pcs 57,000 CHF	~ 3,500 pcs 40,000 CHF
Safety Stock	4000 pcs	1900	1500
Inventory: Turgi	~ 7,200	~ 4,100	~ 3,300
Inventory: PL	n.a.	~ 900	~ 200
Overall Improvement Inventory		32%	51%

Figure 14: Resistor Housing Case Study Summary of Results

These factors led to a revised proposal by the author, which revised the packaging strategy for the component to address the opportunities presented by the pattern of use. This proposal recommended eliminating the use of returnable SBB rail containers in favor of a standard pallet with 24 40cm x 30 cm boxes delivered per pallet. This proposal allowed the supplier to maintain their approximate batch and delivery sizes, but allowed ABB to distribute the stock to the multiple use locations in smaller quantities without repacking.

After evaluation in the continuous review policy model, it became clear that this proposal would yield significant savings to the firm. All in all, the proposal would allow for a 51% reduction and a significant reduction in annual operating costs.

4.4 Summary of Findings

As seen in the case studies detailed in the previous sections of this thesis, the Economic Order Quantity and Continuous Review Inventory Policy provides opportunities for savings in both this project's major arenas of study. The application of stock-based principles to currently order based parts demonstrated savings of 15 -20% when compared to system cost if the parts had remained order based. Additionally, having these parts on stock significantly reduces the chances of shortages at the assembly floor, which will contribute to high overall assembly system utilization and efficiency.

In the second case study, the power of efficient inventory management and insightful packaging was demonstrated. In this case, simply modifying the inventory management principles would have reduced working capital investment by 32%. Adding a packaging change that would allow for order quantities to more closely match the economic order quantity, and allow for smaller work in process stocks throughout the multiple use locations, would reduce the required working capital investment by an additional 19% to a total of a 51% reduction over the current levels.

Through the iterative analysis of several commodities associated with the Splugen project, three major characteristic categories of the supply chain were identified as areas where strategic initiatives could have significant impacts on the total operating cost of the supply chain. First, through analysis of a number of commodities, it was noted that packaging strategy, specifically container sizes offered significant opportunities for performance improvement within the EOQ/Continuous Review Inventory Management Context. Secondly, EOQ and Safety stock sensitivity to inputs such as lead time and variability provide quantifiable opportunities for cost effectiveness improvements through strategic actions such as sourcing changes. Finally, the supply chain's sensitivity to demand and demand variability provide additional financial incentive to standardize commodities across configurations and models to benefit from economies of scale in purchasing and within the supply chain operations.

4.4.1 Packaging Strategy

The resistor housing case study demonstrated the value that can be captured by evaluating packaging size and its impact on the operating costs of the supply chain. The two main factors that allowed for this level of improvement were:

- Smaller package quantities allow actual order quantities and safety stock level to more closely approximate the economic order quantity and safety stock levels recommended by the continuous review inventory policy.
- Smaller package quantities increase the flexibility and divisibility of the company's stock, thereby allowing a significant reduction in the amount of inventory located lineside rather than in the flexible supermarket and warehouse locations.

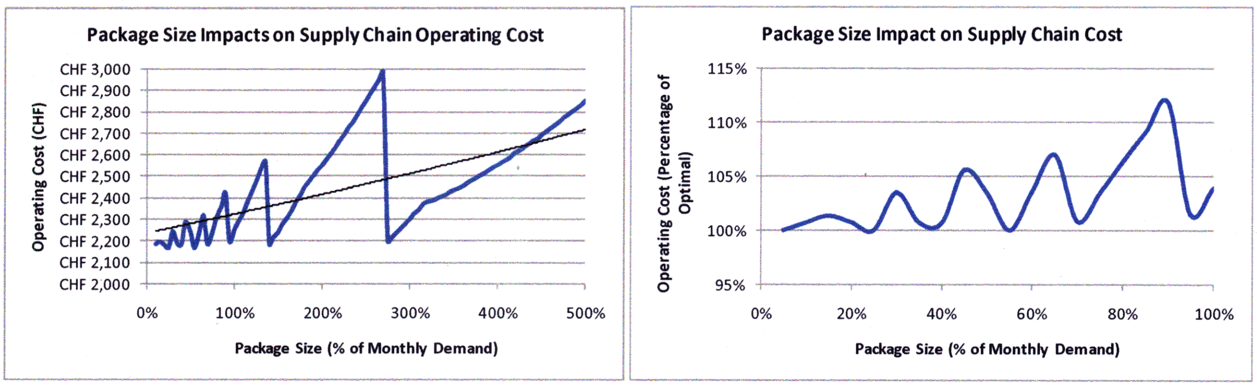

Figure 15: Impacts of packaging size on supply chain operating costs.[13] Note that the right figure is a detailed view of the package size range from 0% to 100% of monthly demand

While these results are promising, it should be noted that blindly reducing the package size for a given commodity does not guarantee improved performance from a cost perspective, even when ignoring key cost drivers such as potential increases in packaging costs from vendors, additional shipping costs resulting from reduced shipping density, increased handling costs or increased holding costs driven by decreased storage density. Figure 15 demonstrates this paradox well. This figure shows the impact of package size on supply chain operating cost when all other variables are held constant. While it is clear that operating costs trend upward as package sizes increase, it is important to note that there are a number of local minimums that closely approximate the optimal. The oscillations in operating cost in the right figure can be directly attributed to the fit of package size. By recognizing this phenomena and the flexibility it provides, sourcing managers can work with suppliers to find mutually beneficial solutions that potentially allow suppliers to maintain batch sizes

[13] Operating costs include order cost, shipping cost, holding costs of inventory and weighted cost of capital.

and minimize additional costs in the packaging and transport areas that will inevitably be passed on to the sourcing company.

4.4.2 Supply Chain Sensitivity to Lead Time

The performance of a supply chain is highly dependent upon both the actual lead time for delivery of commodities and the variability of that lead time. While factors associated with lead time don't impact the ordering patterns of the firm, they have significant impacts on the levels of safety stock employed by the firm to ensure continuous supply of commodities to assembly operations. Illustrative examples that closely resemble the performance characteristics of some commodities in the Splügen supply chain, as shown in figures 16 and 17, demonstrate the impacts that increased lead times and lead time variability have on operating costs and inventory levels for firms. When considering establishing operations in foreign lands and effectively distancing operations from suppliers the following implications are important to consider:

- Increases in delivery lead time translate into operating cost increases at a near linear rate of approximately 15-25% of lead time increases for small increases in lead time, while larger increments lead to non-linear changes. For instance if a commodity had a two week lead time which was increased to three weeks due to supply chain design changes associated with relocating operations to another country it could be reasonable to expect an operating cost increase of approximately 10%, which would be attributable to the change in safety stock levels alone.

- Increases in variability of delivery lead time variability, likewise, have impacts on supply chain operating costs in the form of increased holding costs associated with increased levels of safety stock. Similarly, to lead time increases, increases in the standard deviation of lead time seem to increase operating cost by 15-25% of the increase for small increases.

Given these factors, companies establishing international operations are incentivized to utilize strategies to minimize the impact new operations have on lead time and lead time variability. Some strategies that should be considered are as follows:

- Consider local sources whenever possible to minimize the increase in lead time associated with the actual shipment of commodities.

- Minimize lead time variability by employing efficient customs clearing houses to ensure first time customs clearance and reduced overall lead time. Within the context of the European Union a number of providers exist with localized expertise.

- Work with suppliers to understand lead time drivers and establish incentives for consistently on time delivery.

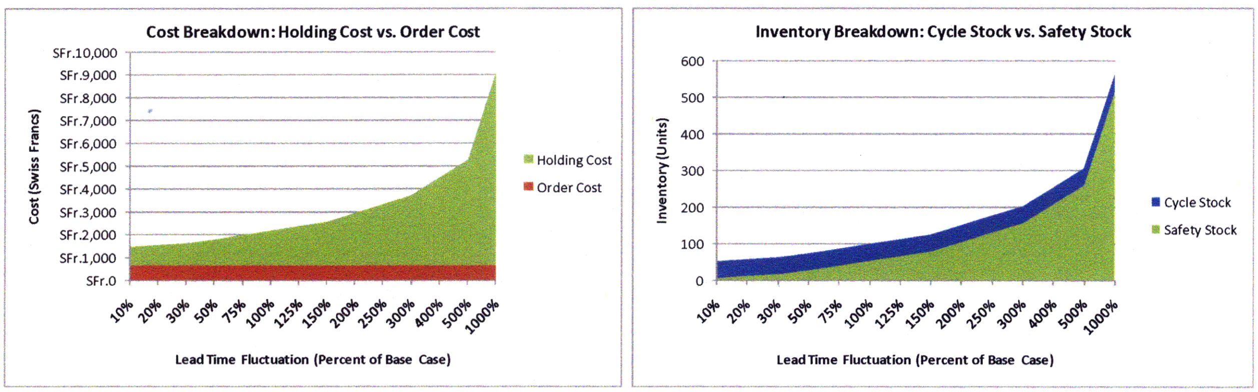

Figure 16: Impact of delivery lead time on supply chain costs

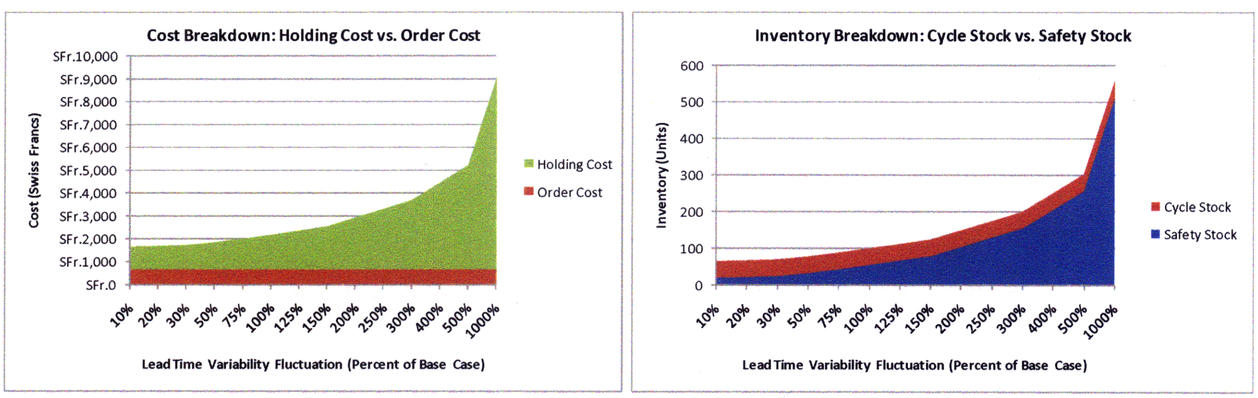

Figure 17: Impact of delivery lead time variability on supply chain costs

4.4.3 Supply Chain Sensitivity to Shipping & Order Costs

Whereas lead time and lead time variability drive costs because of their affects on the safety stock levels of the supply chain, fixed costs, such as shipping and order costs, drive costs both in transaction expense and increased cycle stock levels. The increased transaction expenses associated with each purchase incentivize the purchase of larger quantities of stock, hence driving cycle stock and average inventory levels higher. Figure 18 illustrates this phenomenon, showing that while fixed costs increase, both holding and transaction costs increase, driving logarithmic growth in total supply chain operating costs. By examining the data, it is easy to see that a 25% reduction in fixed costs results in a 10% overall reduction in supply chain operating expense. This pattern of behavior suggests that when establishing foreign supply chains several strategies to reduce these costs should be considered, such as:

- Quickly phasing in local suppliers to minimize transaction costs associated with procuring and shipping goods to the new facility.
- Employing experienced and cost efficient customs clearing houses or suppliers with multinational supply chain experience to minimize additional fixed order costs.
- Developing cost effective electronic ordering mechanisms with the entire supply base to reduce transaction cost.
- Optimizing shipping throughout the supply chain by utilizing strategies such as cross docking and order consolidation at 3rd party logistics providers or other points in the supply chain.

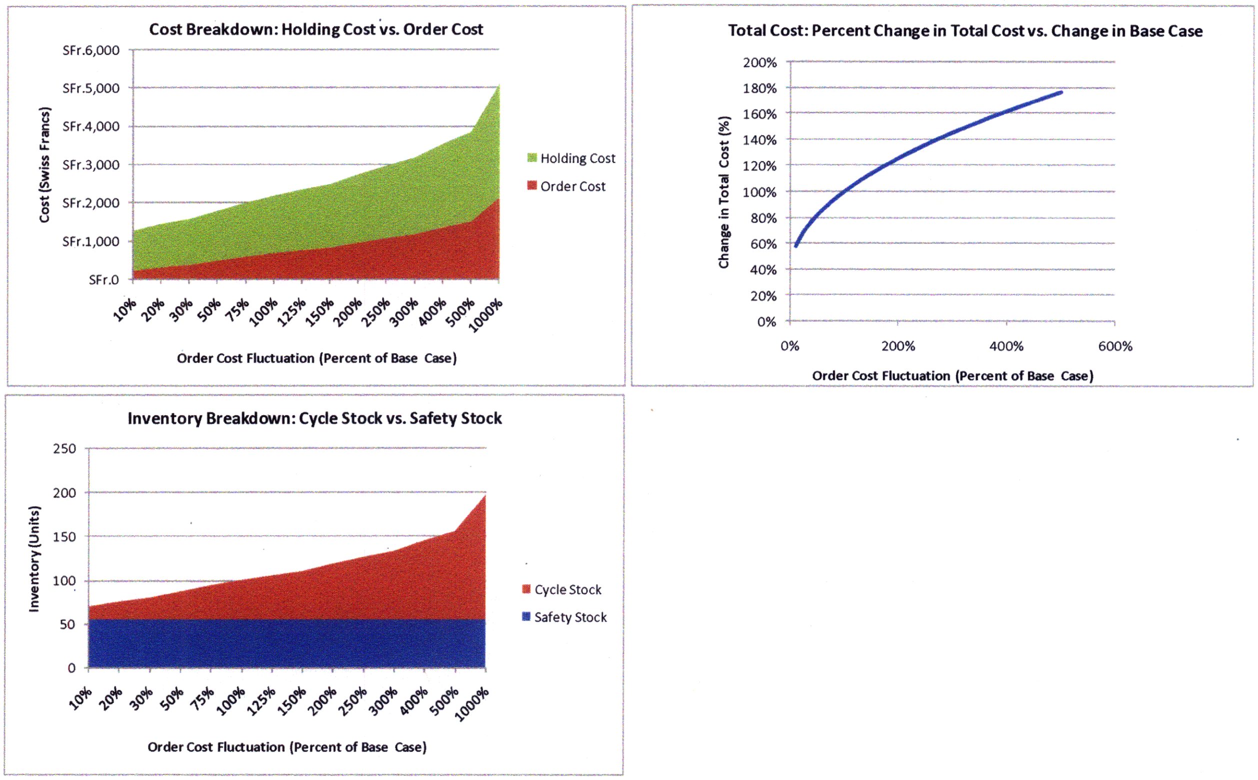

Figure 18: Impact of fixed costs (order and shipping) on supply chain operating costs

4.4.4 Supply Chain Sensitivity to Demand and Demand Variability

Economies of scale exist in the supply chain operations of firms, partially due to the impact that increasing demand has on relative variability for component demands. As seen in figures 20 and 21 operating costs of the supply chain increase at a significantly slower rate than the increases in demand or standard deviation of demand within the supply chain. While firms cannot necessarily control the demand for their products or particular configurations of those products, efforts to consolidate demand for individual components is a viable strategy to minimize variation across configurations.

Illustrative examples demonstrate that standardizing components that are currently split 25%-75% across configurations can reduce the operating costs of the supply chain by up to 20% due to the reduction in variation that is achieved. The savings can grow significantly when the penetration of the low running option is even lower, and as such this strategy should be considered when price premiums do not offset savings. This practice is often discussed as a design for manufacturing initiative because of the benefits component reduction and build complexity reduction provide to shop floor workers. However, here it is possible to see that the benefits of these initiatives extend beyond the line to supply chain operations as well.

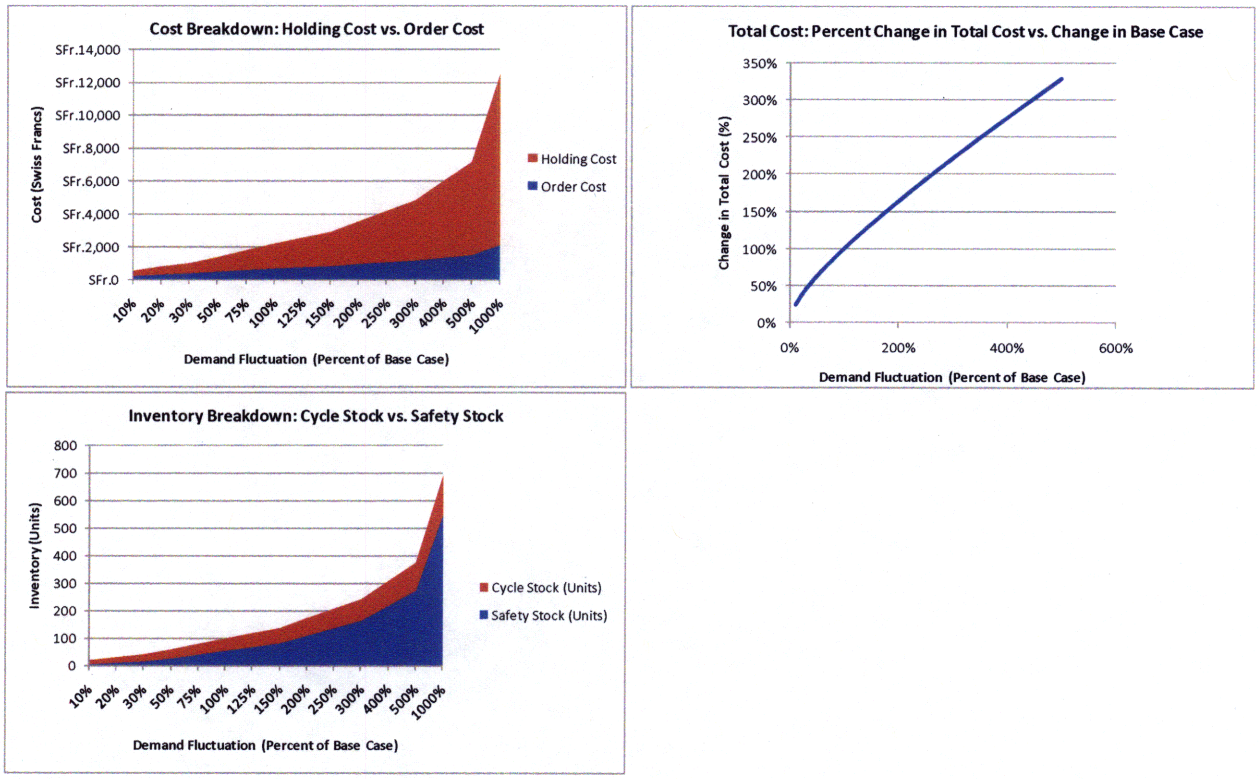

Figure 19: Impact of demand fluctuation on supply chain operating costs

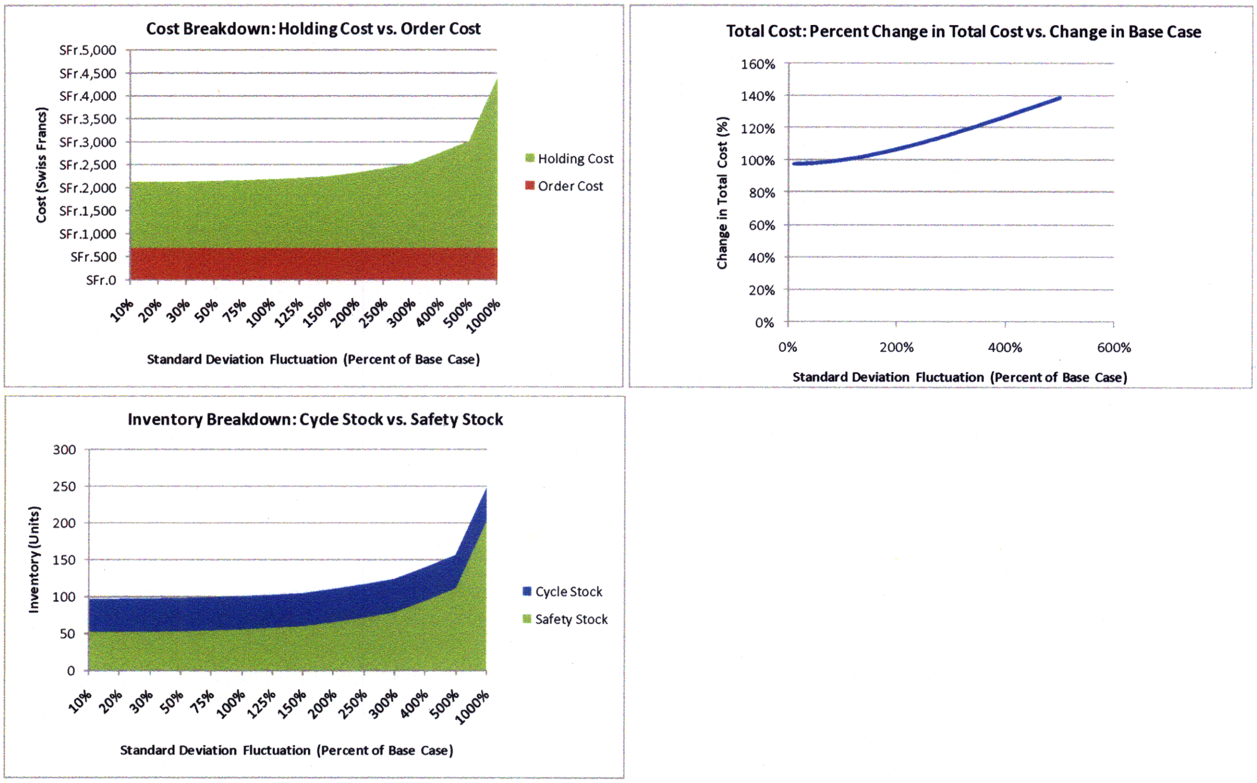

Figure 20: Impact of demand variability on supply chain costs

4.4.5 Conclusion

In closing, the thesis demonstrates the power of the analytical models employed to generate operating cost savings in the procurement and management phases of supply chain operations. Through the course of the sensitivity analysis, it was demonstrated that intervention in the design of packaging and other supply chain performance parameters could positively impact the operating cost of the supply chain. In analyzing the packaging strategy of representative components, it became clear that there was generally a cost penalty associated with increased package size, but that there often existed a number of local minima that yield results within 2-3% of the optimal performance level. Supply chain sensitivity to lead time and lead time variability was demonstrated to be nearly linear when incremental changes were made and increased costs resided between 15-25% of the increases. Shipping and order costs demonstrated an eventually asymptotic impact on supply chain operating costs which should motivate firms developing international supply chains to migrate to local sources quickly to avoid increased costs. Finally, through the course of the case studies, it became clear that the implementation of continuous review inventory policies with demand forecasting techniques posed significant opportunities for cost savings in most component categories.

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APPENDIX 1 : Supplier Packaging & Shipping Quote Proposal Request

ABB

Supplier Packaging & Shipping Quote Proposal
Medium Voltage Drives

Supplier Information

Company Name :

Contact Name :

Title :

Phone :

E-mail:

Component Information

ABB Part Number:
[illegible]

Description:

Country of Origin:

EU Common Nomenclature Code:

Cost per piece: *(include currency)*

Packaging Proposal Data

Proposed Package Type:

☐ Small Box (17 cm x 17 cm x 17 cm)

☐ Medium Box (27 cm x 27 cm x 27 cm)

☐ Standard Pallet (80 cm x 120 cm) – Height of Pallet: cm
(If standard pallet, include height of shipping unit in cm)

☐ Other: Description:
Dimensions: Length: cm Width: cm Height: cm
(If other, include description and dimensions of packaging unit in cm)

Quantity contained in standardized shipping container: pieces

Weight of standardized shipping container: kg

Load limit of standardized shipping container: kg
(ie. Amount of weight that can be stacked upon the package)

NOTE: Please attach photographs showing internal material layout and clearly demonstrating any dunnage or protective packaging between layers.

ABB Switzerland Ltd

Medium Voltage Drives
[illegible]
CH-[illegible] Turgi, Switzerland

Appendix 1: Continued

Supplier Packaging & Shipping Quote Proposal
Medium Voltage Drives

Order Cost Information

Current Order Cost: per order
(Please note if order cost is calculated based on order quantity or other factors. Include Currency. Do not include cost of goods)

Proposed Order Cost: per order

Reason for change in order cost *(if applicable)*:

Shipping Quote: Supplier to Spreitenbach, Switzerland

Shipping Cost: per shipment *(include currency)*

Full or Partial Truck Load: ☐ Full ☐ Partial

Shipping Provider:

Shipping Distance: km

Shipment Weight: kg

Number of Packages in Shipment: packages

Assumptions:

Shipping Quote: Supplier to Lodz, Poland

Shipping Cost: per shipment *(include currency)*

Full or Partial Truck Load: ☐ Full ☐ Partial

Shipping Provider:

Shipping Distance: km

Shipment Weight: kg

Number of Packages in Shipment: packages

Assumptions:

ABB Switzerland Ltd

Medium Voltage Drives
[illegible]
CH-[illegible] Turgi, Switzerland

Appendix 2: Supplier Packaging & Shipping Quote Proposal Guidelines

Supplier Packaging & Shipping Quote Proposal Guidelines
Medium Voltage Drives

The document below details the guidelines for supplier development of packaging and shipping quotes.

Packaging:

In order to support the standardization of the ABB supply chain, suppliers should prepare a proposal for the packaging of each component delivered to ABB Schweiz AG. Packaging proposals should include multiple photographs of the internal configuration of materials and meet the following guidelines:

- The shipping package selected should be one of the three standard containers outlined in the packaging proposal form.
  - Small Box (17 cm x 17 cm x 17cm)
  - Medium Box (37 cm x 27 cm x 27 cm)
  - Standard Pallet (80 cm x 120 cm)

  Deviations from these standard packages will only be tolerated if product characteristics prevent their use. If for some reason a standard package cannot be used for an individual commodity please include and explanation as to why in the Packaging Proposal form.
- In determining the shipping package to be used for a particular commodity, suppliers should attempt to limit the quantity contained to no more than 2 weeks of demand. For instance if in calendar year 2007 ABB ordered 1000 pieces of a particular commodity, the supplier should limit the quantity contained in the proposed package to 40 pieces ((1000 pieces demanded / 50 working weeks total) x 2 weeks of demand). Packages containing smaller quantities are welcome.
- Part presentation in the containers should allow for easy access to the components in the package. Internal protective packaging should provide adequate protection for normal wear and tear experienced during the shipping process but should still allow for easy access to components and should not require elaborate unpacking procedures.
- Packaging Performance: Proposed packaging must meet the following weight and load requirements:

Category	Medium Box	Small Box
Size [cm]	37 x 27 x 27	17 x 17 x 17
Weight Limit	20 kg	10 kg
Load Requirement	60 kg	40 kg

ABB Switzerland Ltd

Medium Voltage Drives
[illegible]
CH-5300 Turgi, Switzerland

Appendix 2: Continued

ABB

Supplier Packaging & Shipping Quote Proposal
Medium Voltage Drives

Shipping Quotes:

Shipping quotes provided by suppliers should include quotes for shipments of projected order quantities to both ABB's Spreitenbach, Switzerland and Lodz, Poland facilities. This information will be used to optimize the transportation strategies for ABB's supply chain.

Supplier quotes should be for shipments based on preliminary estimates of Economic Order Quantities (EOQ). The table below provides an estimate for the Economic Order Quantity for a component that is used only once in each CBU module.

Value of Part	EOQ	Value of Part	EOQ
2000 CHF	25-30	300 CHF	45 – 55
1000 CHF	35-40	200 CHF	65 – 80
		< 100 CHF	100 – 120

To calculate the estimated EOQ for an individual component a supplier should scale this quantity based on the square root of average commodity use per module.

For instance, if a supplier provided a part valued at 1000 CHF that was used 6 times in each module the estimated EOQ would be as follows:

$$\text{Estimated EOQ} = \sqrt{ComponentUsePerModule} \times \text{Base EOQ}$$

$$\text{Estimated EOQ} = \sqrt{6} \times 35 = 85 \text{ pieces}$$

Please note that if there is an optimal batch size at the supplier site, ABB could be interested in ordering commodities in that quantity. If that is the case, please attach an alternate shipping quote for those quantities in addition to the quote for the ABB proposed EOQ.

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Medium Voltage Drives

CH-5300 Turgi, Switzerland