

Applying an Analytical Framework to Production Process Improvement

by

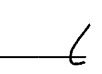
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Submitted to the Department of Civil and Environmental Engineering
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The MIT Sloan School of Management
In Partial Fulfillment of the Requirements for the Degrees of
Master of Science in Civil and Environmental Engineering
Master of Business Administration

In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2007.

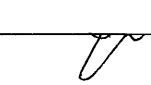
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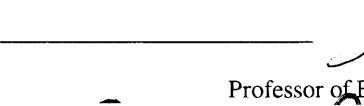
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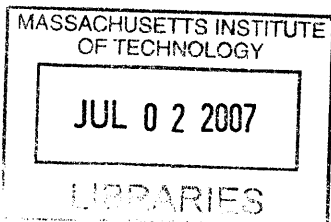


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Curtis J Underwood
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1 Abstract

As the medium voltage switchgear industry moves from air insulated to gas insulated technology, Siemens Frankfurt factory is introducing a new gas insulated product line that will improve their relative market position. It is their intent to design a product and supporting production system that will enable substantial cost and lead time reduction over existing Siemens gas insulated switchgear products. This thesis outlines a framework for analyzing the existing production process from 'customer order to customer delivery', identifying areas of opportunity, valuing projects aimed at achieving these opportunities, and prioritizing highest value projects for implementation.

To provide a rigorous analytical approach to project selection, it was important to rethink existing ways of valuing inventory holding costs, material handling costs, and lead time. By uncovering hidden costs and benefits for each, projects that otherwise seemed unattractive become important to achieving overall factory objectives. Conversely, other projects that had been historically pushed by factory leadership were shown to generate little overall return on investment. By using the approach outlined in this thesis, improved alignment was achieved across departments on several high value projects. This alignment positioned the factory to move forward with plans for successful implementation. It is the authors' hope that Frankfurt not only finalizes implementation of high value projects identified during this analysis, but also use the framework provided for future analysis and continued improvement.

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2 Acknowledgements

As with any meaningful undertaking, the support of many is a fundamental requirement for success. Our work on this thesis is no exception.

We want to thank Siemens for supporting our internships. We especially appreciate the opportunity to work with the Projekt Portfolio 2008 team and their patience as we learned how to work and communicate in this new environment. Willi Heidenreich was particularly helpful both in his support of our work and in helping to ease our transition to life in Germany. Dr. Jörg Teichman and Dr. Ludger Werth were also instrumental to the project. Throughout our work, factory management, especially Factory Manager Hr. Claus Thurau, ensured that support was available throughout the organization.

The Leaders for Manufacturing Program at MIT has played a central role in molding our thinking about manufacturing, how to spot problems and most importantly how to lead an organization toward improvement. The commitment to this program by professors, our peers, administrative staff and corporate partners has been extraordinary. We are indebted to Professor Stephen Graves, whose keen insights helped to focus our efforts and eventually produce this document. We would also like to thank Professor David Simchi-Levi for assisting our work through his previous publications and helping us to consider our work in the context of those who came before us.

Curtis Underwood & Jacob Wood

Throughout the LFM program, I have benefited greatly from the support of my beautiful wife, Patti. Her support did not wane when we moved for the second time and figured out how to survive in Germany together. My family has always been important in maintaining balance in my life. Their support (Underwood's and Crowley's) is greatly appreciated.

Curtis Underwood

I am grateful to my lovely wife, Kathy. Her sacrifice and unending patience have made the LFM journey possible. I truly believe her name should be next to mine on the MIT diploma. Finally, I want to thank my wonderful daughter, Maggie, who has given me the gift of perspective.

Jacob Wood

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3 Table of Contents

1	Abstract.....	3
2	Acknowledgements	5
3	Table of Contents.....	7
4	Table of Figures.....	8
5	Introduction	9
5.1	Company Overview.....	9
5.2	Product Overview.....	10
5.2.1	Switchgear Technology	10
5.2.2	Air Insulation versus Gas Insulation.....	11
5.3	Business Overview.....	12
5.3.1	Environment	12
5.3.2	Portfolio 2008.....	13
6	Project Introduction	15
6.1	Business Problem Statement	15
6.2	Approach - Pyramid of Phases	15
7	Current State Analysis	19
7.1	Process Flow	19
7.2	Order Processing	19
7.3	Pre-Production.....	22
7.3.1	Parts Warehouse	23
7.3.2	Core Part Assembly	24
7.3.3	Circuit Breaker Production	24
7.3.4	Final Assembly	24
7.4	History of Lean initiatives at the Frankfurt Factory	25
7.5	Methods.....	26
7.5.1	Process Maps	26
7.6	Insights From Current State analysis.....	30
8	Project Valuation	35
8.1	Opportunity Analysis	35
8.2	Costs of Machine Setup and Inventory Handling.....	36
8.2.1	Project Application – Kanban Conversion.....	37
8.3	Cost of Holding Inventory.....	41
8.3.1	Project Application – Safety Stock Evaluation.....	42
8.4	Lead Time Valuation.....	47
8.4.1	Project Application – Laser Welding Production Planning	48
8.4.2	Lead Time in terms of Euro value	50
8.4.3	Project Application – Exact Parts	52
8.5	Lead Time Variation	55
8.6	Factors Without Discrete Valuation	57
9	Our Struggle – Analytics versus Lean Philosophy	59
10	Next Steps	62
11	Summary	63
12	Appendices.....	66
13	Bibliography.....	74

4 Table of Figures

FIGURE 1 – POWER DISTRIBUTION	9
FIGURE 2 - 8DH PRODUCT (LEFT) AND 8DJ PRODUCT (RIGHT)	10
FIGURE 3 - SWITCHGEAR COREPART	11
FIGURE 4 - GIS SECONDARY MARKET SHARE	13
FIGURE 5 - 3 PHASES OF THE PROJECT	16
FIGURE 6 - THE PROCESS FLOW FOR SIEMENS' 8DH AND 8DJ MEDIUM VOLTAGE SWITCHGEAR	19
FIGURE 7 - PROCESS MAP FOR 8DJ PRODUCT ORDER PROCESSING.	28
FIGURE 8 - ORDER PROCESSING FOR ALL 8DH ORDERS CAPTURED IN CHINA	32
FIGURE 9 - 8DJ PRODUCT TRANSITION FROM CORE-PART ASSEMBLY TO FINAL ASSEMBLY	33
FIGURE 10 - FACTORY KANBAN FLOW	37
FIGURE 11 - WAREHOUSE COST ANALYSIS	40
FIGURE 12 - STOCKOUT CONSIDERATION	44
FIGURE 13 - EXPLORATION OF SERVICE LEVEL	45
FIGURE 14 - LASER WELDING SEQUENCE ANALYSIS RESULTS	49
FIGURE 15 - LEAD TIME VALUATION BREAKDOWN	52
FIGURE 16 - AVERAGE TIMELINE FOR 8DJ PROCESS	52
FIGURE 17 - ACTUAL TIMES FOR 8DJ FROM FRANKFURT'S M2 TOOL	53
FIGURE 18 - PROCESS VARIATION AND EXACT PARTS	54
FIGURE 19 - PROCESS VARIATION ANALYSIS FOR 8DJ FOREIGN SALES ORDER PROCESSING	57

5 Introduction

5.1 Company Overview

Siemens AG is one of the largest multinational companies in the world. With 6 product divisions Siemens provides products and services ranging from medical devices to power generators. The Siemens Power Transmission and Distribution group (PTD) of the Power Division represents 7% of Siemens total revenue with over 56 locations throughout the world and over 25,000 employees.¹ Headquartered in Erlangen, Germany, PTD is responsible for producing a wide range of power switching equipment like switchgear components, protection and control devices. This product group can be further broken down by product type. Power Transmission and Distribution Products are first distinguished as High (72.5 to 765 kV) or Medium Voltage (3.6 to 52 kV). As the name suggests, high voltage switching products are designed for the purpose of switching and protecting power from the point that it is stepped up to high voltage for long distance transmission, to the point that it is transformed down in voltage for supply to private and industry consumers.

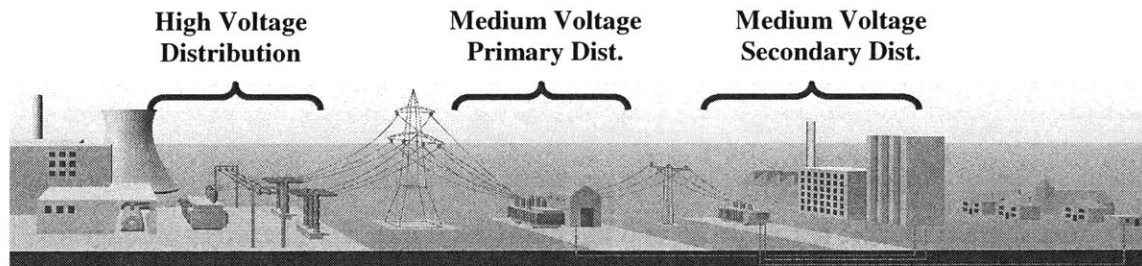


Figure 1 – Power Distribution

The focus of this analysis rests specifically within the Medium Voltage Product group. Medium Voltage products represent approximately 20% of the total PTD revenue (or 1.6 billion Euros in 2006). Medium Voltage products are produced in 16 factories by nearly 5,000 employees throughout the world. Further, Medium Voltage products are divided by those that serve primary distribution services or those that serve secondary distribution, located near to the end consumer as in residential areas. The distinction between primary and secondary distribution is not central to this analysis and represents slight differences in voltage ratings and switching capability. The focus of this analysis falls exclusively in the range of secondary distribution switchgear products.

Finally, the switchgear market is further segmented by product technology. Within the Medium Voltage market, products are divided by Air Insulated and Gas Insulated Technology. Section 5.2.2 provides a further description of air versus gas insulated technology. At this time, Siemens manufactures nearly all medium voltage gas insulated switchgear at its facility in Frankfurt, Germany. With roughly 800 employees, the Frankfurt Factory produces switchgear for customers worldwide.

5.2 Product Overview

5.2.1 Switchgear Technology

Switchgear is considered to be a collection of power switching devices and fault protection devices that enable the supply of power within a distribution network. Switchgear is used primarily for two purposes. First, when coupled with circuit breaker technology it can be used to detect short circuits and protect the remaining network by breaking the connection to the faulty section. Second, switchgear is used to isolate sections of the network for maintenance and repair. At the core of each switchgear device is a number of 3 phase switches designed to switch off the current fast and reliably. Additionally, fuses and circuit breakers are incorporated with a series of voltage and current monitoring systems.

For Siemens Frankfurt factory, the two flagship products in the Gas Insulated, Medium Voltage, Secondary Distribution market are the 8DH and the 8DJ (see figure 2). The 8DH product line is a highly configurable product. The 8DH product can be ordered in a modular fashion with numerous functional ‘panels’ attached side by side. This creates an unlimited number of 8DH configurations. Additionally, the 8DH product offers a complete line of voltage and current monitoring through low voltage panels attached above the primary units.

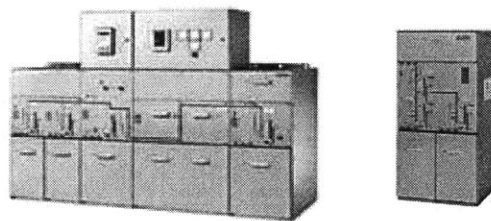


Figure 2 - 8DH product (left) and 8DJ product (right)

The 8DJ, by contrast is a simple and standardized product offering. The 8DJ has a limited range of possible configurations. Additionally, low voltage compartment offerings are far more limited than with the 8DH product. Based on its simplicity relative to the 8DH, the 8DJ is cheaper to produce and priced lower than the 8DH.

5.2.2 Air Insulation versus Gas Insulation

For years, the dominant technology in medium voltage switchgear was air insulated switchgear. This means that the actual 3 phase switchgear mechanism is exposed to the atmosphere. To maintain sufficient insulation distance between energized circuits, quite large design dimensions are necessary with air insulation technology.

In 1982 Siemens introduced its first gas insulated medium voltage switchgearⁱⁱ. Since that time, demand for gas insulated switchgear has grown in the marketplace. Gas insulated switchgear are encased in sealed vessels filled with SF₆ gas. The vessels has to be “sealed for life”, which means tightness for more than 30 years without any refilling. The insulating properties of this gas are far superior to air and, thus allow for compact and maintenance free switchgear. Additionally, the fully enclosed gas insulated switchgear is superior in protecting the core components from atmospheric conditions. This is especially beneficial in extreme climate conditions such as coastal, desert, and jungle conditions. Figure 3 depicts a Siemens gas insulated vessel, housing the core switchgear and switching devices.

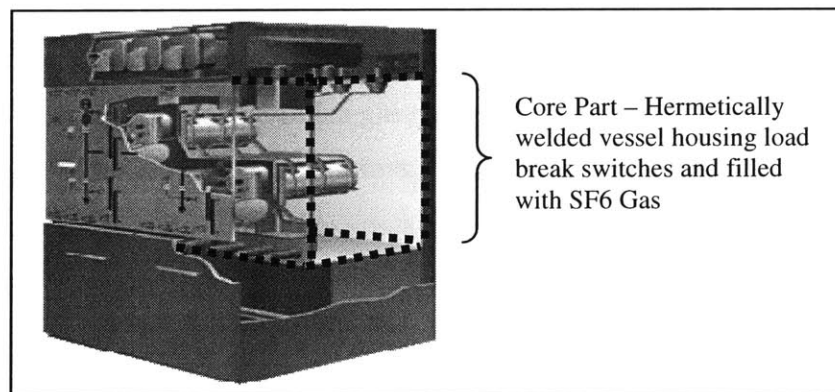


Figure 3 - Switchgear Corepart

5.3 Business Overview

5.3.1 Environment

Siemens PTD initially entered the switchgear market with its line of high voltage and primary distribution products. These products sell mostly to power producers as well as public and private electric distribution utilities. For these customers, functionality and reliability are of higher priority than lead time and low price. Therefore, Siemens focused on developing competitive advantage through superior product engineering, strong technical support, engineering services and customization. Customers were willing to spend 3 to 4 months in the custom design phase and, therefore understood that a product with such customization would be more expensive and time consuming to build.

This superior quality design and customer facing engineering support became the cornerstone of the medium voltage business as well. Initially, Siemens leveraged its high voltage customer base to establish a presence in the medium voltage, secondary distribution market. Focus in this new space started with their existing group of customers, which excluded several large customer groups, such as resellers and end-users. Siemens' widely recognized brand and reputation for quality helped it establish a strong position among end-users of medium voltage products. However, the needs of resellers and wholesalers are of lower importance in the Siemens medium voltage product slate. These customers are essentially systems integrators, purchasing individual switchgear and then integrating the necessary components to establish turn-key project solutions. These customers are sometimes in indirect competition with Siemens value proposition to provide detailed design and engineering solutions for the customer. These integrated power transmission solutions sell at a premium and can generate heavy volumes. However, these customers are less interested in customized components and more focused on price and lead time. Due to the existing utility and industry oriented sales organization, Siemens left this commoditized market to other manufacturers.

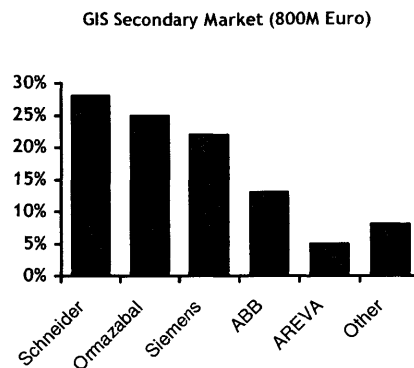


Figure 4 - GIS Secondary Market Share

In the last 5 years, the medium voltage switchgear market has seen higher growth rates for gas insulation technology than for air insulation technology. As this development continues to unfold, it is clear that most all major players in the switchgear industry are taking steps to capture more of the gas insulated market than they previously held in the air insulated market. This developing GIS market is the driver for Siemens' Portfolio 2008 initiative.

5.3.2 Portfolio 2008

The Portfolio 2008 team was established in an effort to design and bring to market a new line of Secondary Medium Voltage Gas Insulated Switchgear. This new product line would replace both the 8DJ and 8DH product lines. The team was given aggressive goals for production cost reduction as well as softer directive to reduce customer lead time. In this way, Siemens hoped to capture an appreciable portion of the wholesaler market.

The team, comprised largely of product design engineers, was functionally organized into 4 groups that targeted a full redesign of their respective switchgear function. To keep the functional teams sufficiently integrated, all designers worked in a common office space that facilitated cross functional collaboration. Additionally, the team included members that focused on linking the effort to other parts of the organization. A sales representative focused on bridging the Portfolio 2008 efforts to the entire Medium Voltage Sales operation. Moreover, a small team of manufacturing engineers worked closely with the manufacturing staff of the Frankfurt Factory to incorporate design for manufacturability principles into the design process.

It is this manufacturing group of the Portfolio 2008 team that served as home base for the analysis to follow.

6 Project Introduction

6.1 Business Problem Statement

The underlying objective associated with this internship can be quite simply stated as follows:

1. Analyze the Gas Insulated Switchgear process from ‘*Customer Order to Customer Delivery*’ for the 8DH and 8DJ product lines.
2. Provide recommendations that will enable reduction in cost and lead time on the focus products today and to help bridge the gap for the rollout of Project Portfolio 2008.

Since the project was chartered by the Portfolio 2008 team, the primary interest of this analysis was to benefit the introduction of the new product lines. These recommendations would help enable a smooth product introduction into the market at a sufficiently competitive price point and with lead times that would attract increasing interest from the wholesale market. However, it is clear that the analysis of the complete value chain for the existing 8DJ and 8DH product lines would offer tremendous value, both for the remaining life of these products as well as key learning for other existing products manufactured in the Frankfurt factory. For this reason, the Frankfurt factory management was jointly invested in this analysis for their own continuous improvement and future success.

6.2 Approach - Pyramid of Phases

Given the incredibly wide scope of the project as well as the offset timing of the primary project leads, it was paramount that the project be defined in a structured manner that would facilitate a clean transition from project lead to project lead. The project was organized in three distinct steps, each spanning a three-month time frame. The first phase would create a foundation through current state process mapping and data collection. Jacob Wood led this phase. The second phase, a joint effort by Jacob Wood and Curtis Underwood, would analyze the current state information, identify areas of opportunity, and perform ROI analysis on each. The third phase would focus on implementation of the most attractive projects. Curtis Underwood led this final phase.

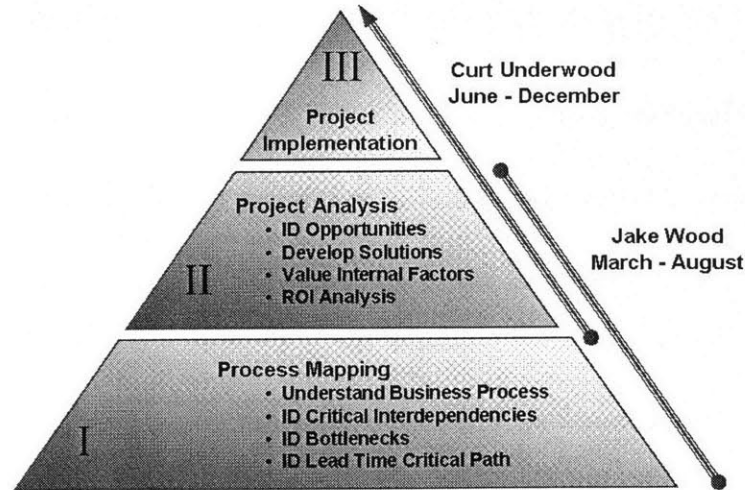


Figure 5 - 3 Phases of the Project

Phase I:

Principally a process mapping exercise, Phase I established the foundation of information necessary to completely understand the value chain. This process mapping incorporated the entire business process associated with the 8DH and 8DJ product lines from the initial customer order capture to the final delivery of the completed switchgear. From this effort, an in-depth understanding of the process was gained and potential areas of opportunity were identified.

Phase II:

Building on a sound understanding of Siemens switchgear manufacturing and business processes, the focus shifted to quantification of the opportunities shown by phase I. In order to quantify these opportunities, the cost structure of the product and the facility were studied, uncovering many hidden costs. Previously under-explored valuations of product lead-time, holding cost, and internal handling were conducted through rigorous analytical methods.

More than 20 potential improvement opportunities were developed and vetted through a series of steps. These steps comprise a proposed framework for addressing a value chain analysis of this magnitude.

Identify Areas of Opportunity: Simply identify the fact that an opportunity exists for improvement to the process from a cost or lead time point of view.

Quantify the Opportunity: Perform the necessary analysis to understand the potential upside of the identified opportunity. This provides an eye opening analysis to factory leadership of the potential that exists within the process.

Identify Projects that will realize the opportunity: Once an opportunity is understood and determined to be sizeable enough for further exploration, tangible projects are outlined to realize some or all of the defined opportunity. Since this opportunity has been clearly identified, projects are structured to directly target that particular prospect. Through this first stage in the vetting process, some academically interesting opportunities were eliminated when appropriate projects could not be formulated. This framework helped eliminate exciting opportunities that just did not make sense for the specific operation or established factory principles.

Cost/Benefit Analysis: Once projects are identified, it is important to refine the cost benefit analysis and determine the financial return for each project. Taking the time to establish the project level return on investment (ROI) or net present value (NPV) provides the business a tangible means of determining project attractiveness that is far more rigorous than seeking leadership buyoff on projects rooted only in philosophical terms.

Implementation: With the projects defined and characterized, the most attractive projects are selected for implementation. Then the hard work begins. Resources must be allocated and effort deployed to change established work practices on the shop floor. As previous assumptions or estimates are challenged or found to be incorrect, this feedback is iteratively reinserted in this project vetting process as deemed appropriate.

It is clear that following this process was time and resource consuming. However, it is the opinion of the authors that this framework is essential in developing an analytical case for continued process improvement in areas that otherwise have rejected such improvements. The lean efforts approach employed in improving the final assembly area reached organizational and political barriers that prevented further proliferation. The proposed framework above is a methodical way to overcome those barriers through a series of analytical steps that can open the eyes of the most discerning department managers.

Phase III:

Upon completion of phase II, the primary project stakeholders selected the three most attractive projects. Curtis Underwood would drive these projects through implementation. Seven remaining projects were documented and transferred to the appropriate Siemens stakeholders for future implementation.

7 Current State Analysis

This section begins with a brief review of the various aspects of the value chain that will be referenced throughout the thesis. Next, the underlying methods used to complete the current state analysis are examined. Finally, key insights associated with the initial process mapping exercises are reviewed.

7.1 Process Flow

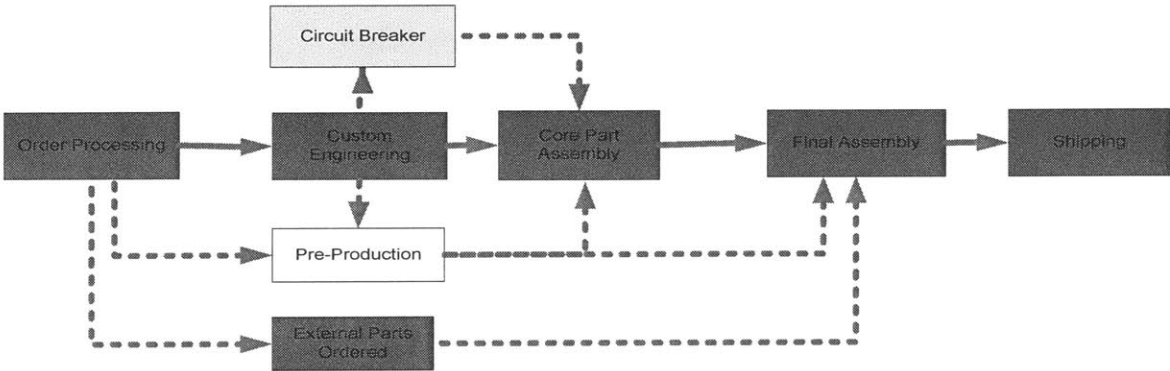


Figure 6 - The process flow for Siemens' 8DH and 8DJ Medium Voltage Switchgear

7.2 Order Processing

Initially, orders for 8DJ and 8DH products taken throughout the world are entered into two primary systems. First, all of the commercial information relevant to the order such as price, quantity, and shipping requirements are collected via SAP. Second, a set of initial technical specifications is recorded in a computer system that houses order specific technical information and product engineering decisions. Once initial data exists in these systems, Siemens Center of Competence begins the necessary order-specific engineering required. This requirement can be as little as zero for highly standardized 8DJ products, to 4 weeks of detailed low voltage wiring design as part of a complex 8DH order with Circuit Breaker technology.

Once the technical and commercial orders are complete, the order processing teams (organized functionally by product type) collect the information and begin the process of merging the data into a single factory SAP system. This SAP system will handle all of the physical inventory tracking, reporting, and ordering for each new order. Additionally, the Order Processing

departments are responsible for entering each order into their M2 computer system, which enables the comprehensive tracking of customer order milestones and performance to these milestones. M2 is used for this purpose over SAP because it allows for the tracking of key order dates that are not commensurate with an action taken on a physical part, such as the completion of a wiring diagram. All remaining activities such as external part ordering, part production, warehouse retrieval, and assembly scheduling are automatically back calculated from the key dates associated with M2 and SAP. While Frankfurt's assembly process is exclusively make/assemble to order, systems for part production are largely make to stock. Part production methods and order processing mechanisms are explained briefly below.

Make to Order:

For highly customized parts (usually associated with highly customized, long lead time orders), production is initiated only after the customer order has been received. Starting with the quoted shipping date, M2 back calculates the required start of assembly date. This date serves as a trigger for all build to order parts. The part production release date is back calculated from the start of assembly date based on the lead time for the part in SAP. Pre-production has the ability to pull in production jobs that have not yet been released, but this is only done on occasion. Once these parts have been produced, they are routinely stored in the central warehouse until retrieved by final assembly. These parts are a small portion of parts made in Frankfurt.

Direct Pull System:

About 1% of Frankfurt's part production volume employs a true pull system called Direct or Eigenfertigung Kanban (E-Kanban). At least two boxes of parts are stored at or near the line. When a box is empty, the kanban card is removed and another is reordered at a nearby computer on the shop floor. SAP schedules a pre-production order, which is released with the next batch of orders (usually once per day). When the box is filled with newly made parts, it is transported from pre-production directly to the final assembly area. The number of parts per box is determined primarily by the box's volume and weight capacity. Historically, only frequently used parts that can be produced quickly (low lead-time) have been converted to E-Kanban.

Indirect Pull System:

Indirect Umlagerung Kanban (U-Kanban) makes up around 20% of Frankfurt's production volume. This type of Kanban is actually two pull systems decoupled by the large warehouse. By decoupling the systems, pre-production can size batches independent of how assembly prefers to receive the parts, allowing them to size batches in a locally efficient manner and reduce setup costs. Multiple boxes of each part are stored in the warehouse, while only 2 boxes are stored at or near the assembly line. As with E-Kanban, Assembly reorders when they empty a box. With U-Kanban however, the box of parts is retrieved from the warehouse and is consistently delivered within one day. More details on methods for calculating necessary safety stock and cycle stock can be found in section 8.3.

Q-R Production:

Most parts manufactured in the Frankfurt plant are still made to predefined stock levels, where SAP manages target levels of inventory in the warehouse. Similar to U-Kanban, though more of a push system, this model requires Assembly to pull needed parts from the warehouse in 1-box increments, while Pre-production can fill the warehouse with multi-box batches. Instead of using kanban orders, SAP releases orders for predetermined batch sizes. SAP uses projected part usage based on the assembly schedule to release orders with the aim of receiving the parts on the day that inventory reaches the target. For example; if the target inventory level is 100 parts, it takes 5 days to deliver a batch of 200 parts, current inventory is 160 parts and projected usage this week is 10 parts per day: SAP would release an order tomorrow, such that in 6 days, when projected inventory is at the target 100 parts, the new batch of 200 parts should arrive in the warehouse.

Straight Push:

Due to certain current capacity constraints, for instance, all resin parts are made to stock using a push system. These parts are produced at near-capacity level production year round and removed from inventory as dictated by seasonal demand variation. Though these parts comprise a significant portion of pre-production, management excluded resin from further exploration

since capacity decisions were viewed as set in the short term and otherwise determined in the long term.

For more information on push, pull, make to stock and make to order, please see Hopp & Spearman *'To Pull or Not to Pull: What is the question?'*.ⁱⁱⁱ

7.3 Pre-Production

Siemens currently manufactures about 40% by volume of the parts that comprise their 8DJ and 8DH products. For these parts, the pre-production process is an organization of process 'islands', each with a distinct function. The following is a brief description of the primary pre-production islands explored in this project.

Sheet Steel: A majority of Frankfurt's pre-production activity centers around traditional sheet steel processes. Various thicknesses and compositions of sheet steel are worked in a combination of laser cutting, punching, bending, high volume stamping, and welding operations. Thousands of different types of sheet metal parts are manufactured through these steps. Each part is assigned a route of specific operations. While the high volume of part varieties can create some challenges operationally, only about 3% of all the part types can not be fit into one of approximately ten relatively standard processing routes. Additionally, almost half of all parts processed through sheet steel production are processed solely through a laser cut or punching operation.

Aluminum: While the aluminum island does not directly produce parts that go into the 8DJ or 8DH products, this production process is a substantial part of the overall logistics of the Frankfurt factory. For this reason, a brief description of the process is offered. The Aluminum Island is a machining process whereby aluminum castings, purchased externally, are machined to tolerance to form interchangeable gas compartments. These aluminum compartments are mostly used in the larger primary distribution products.

Resin: Each switchgear product sold contains a variety of parts designed as insulators against the flow of electrical current. In the 8DJ and 8DH products, these insulators are used as bushings to pass electrical current through the stainless steel core-part enclosures. These bushings are manufactured in a process that fills molds with an insulating resin. This resin molding process is extremely sensitive to a variety of external factors such as mold temperature,

resin temperature, ambient humidity, and cleanliness of the copper inserts into the bushings. Any voids, cracks, or other defects in the bushing could create a leak or possible future leak in the SF6 filled core part of the switchgear. For this reason, the resin process currently employs numerous inspections of each bushing after processing. These tests include bushing leak testing, X-ray inspection to identify voids and cracks, and electrical testing to ensure the bushing effectively transfers current.

Copper: In each of the 8DJ and 8DH products, current is transported throughout the switchgear by way of a rectangular copper bus bar. With the advent of the Gas Insulated Switchgear, manufacturers have configured the core parts to be as small as regulations allow. The copper bus bars inside these products often have several multi-axial bends to fit in this tightly packed space. The Frankfurt Factory uses a combination of 2-D and 3-D bending equipment to make this possible. Copper bar stock is automatically fed into a machine that cuts the bars into desired length and stamps the required connection holes in each end. These individual pieces are then loaded onto the bending machines where they are bent and twisted into the necessary configuration.

Paint: Approximately 25% of all sheet steel parts produced in Frankfurt are then painted before assembly. The Frankfurt Paint operation represents the only operation in Frankfurt that allows external customers to use excess capacity. The painting operation in Frankfurt can be defined as two entities; powder coat and spray painting. The powder coat line is fully automated where unpainted parts are hung on an overhead conveyor and processed. Changing paint colors on the powder coat line is time consuming and requires Siemens to batch parts by like-color to reduce the total number of color changeovers required each day.

7.3.1 Parts Warehouse

One of the primary mechanisms that have allowed Frankfurt Final Assembly processes to develop extensive pull systems has been the parts warehouse. Considering that this factory has not carried their one piece flow philosophy to the pre-production process or the external supplier management processes, the warehouse has acted as a primary buffer between larger scale batch processing and parts delivery and the more synchronous events of final assembly. The impact of warehouse operations on the rest of the processes is further discussed in section 8.2.1.

7.3.2 Core Part Assembly

Once orders have been scheduled for production, the next series of operations involve welding the core part vessel and then assembly of the switchgear into this vessel. Each of the 8DJ and 8DH product lines has their own dedicated core part assembly lines. The core part production process is also discussed in more detail in section 8.4.1 as related to production sequencing improvements. Once the core part has been assembled and closed, the final steps in this process involve the actual filling of the core part housing with SF₆ gas. At this point the core parts are transported to the final assembly lines.

7.3.3 Circuit Breaker Production

For the 8DH product line, approximately half of all products have incorporated circuit breaker technology. These circuit breakers account for nearly x% of the total product cost. For the existing 8DH process, Circuit breakers are produced in a separate factory located in Berlin, Germany. Orders for circuit breakers are submitted from Frankfurt to the Berlin site as part of the SAP parts inventory management process. The Berlin factory maintains an 8 day lead time commitment to the Frankfurt factory and currently makes two truck shipments per day to facilitate lower working inventories of circuit breakers in final assembly.

7.3.4 Final Assembly

Once all necessary components have been produced, external parts have been delivered, and coreparts have been assembled, the switchgear is fully assembled, tested, and packaged for shipment. Overall, this process represents a relative small fraction of the total customer lead time.

Currently, 8DH and 8DJ products are assembled on dedicated lines. Each line is comprised of workstations that contain sets of tasks aimed at achieving station Takt time, or standard pace, of 20 minutes per switchgear panel. Daily assembly schedules are sequenced as needed to minimize the disruptive effect of variable assembly times associated with custom orders. Additionally some orders with extremely high levels of additional assembly content, such as low voltage wiring, are removed from the flow of the assembly line and completed by a single assembler.

7.4 History of Lean initiatives at the Frankfurt Factory

Siemens' Frankfurt Factory has a history of process improvement initiatives that began with the implementation of a traditional lean improvement framework in the final assembly processes of the medium voltage secondary switchgear products (8DJ and 8DH). Included in these improvements was the adoption of such principles as standardized work, kanban based inventory pull systems, use of takt time to create constant assembly line flow. In addition, the Frankfurt factory held regular kaizen events in an effort to foster a continuous improvement mindset throughout. These initiatives were successful in improving overall labor efficiency and cycle time within the final assembly process. To cement these concepts into the factory culture, these principles were captured in the Frankfurt Production System, or FPS.

In the greater view of the entire value chain, these improvement efforts represent islands of success that, if left unconnected, would prevent the Frankfurt operation from achieving desired results.^{iv} Lean improvements had sharp boundaries within the organization that marked where the new way of thinking stopped and the old way of thinking began. Moreover, the boundaries between lean processing and traditional methods represented enormous areas of opportunities. This is most visible in the form of a large inventory buffer of parts that decoupled the pre-production operations and part procurement from the final assembly process. Neither the pre-production or external part purchasing processes fully embraced the above-mentioned lean concepts. As a result momentum from these lean efforts failed to go beyond the assembly parts warehouse. The recently adopted lean principles of the final assembly processes relied on frequent and reliable deliveries of parts on an as needed bases. The surrounding processes, however, were not established to provide such deliveries of parts.

In light of this, and other, barriers to creating a value-chain wide lean system, what could be done to overcome such obstacles? In this assessment, the philosophically driven lean practices must be augmented with sound analytical rigor. It is in this way that discerning managers can best understand the benefits of a more comprehensive transformation. In other words; lean as a mantra had reached as far as it was going to reach. Something was needed to help this organization extend these efforts in a structured, methodical way.

7.5 Methods

The initial current state analysis for this project represented more than a starting off point for the future project phases. It represented a strong desire from the Portfolio 2008 leadership to capture a complete ‘picture’ of the value chain. For this reason, individual process maps were captured in substantially more detail and completeness than would be done in a traditional analysis. This consumed tremendous project resources up front. However, the energy expended was extremely worthwhile in establishing a trust within the organization that these efforts and analysis would be based on more than a cursory understanding of the processes. [Those] who identify a need to bridge silos in technocratic cultures must first build credibility as a discipline specialist before trying to sell cross-functional ideas.^v

7.5.1 Process Maps

The process mapping exercise discussed here had several distinct similarities to traditional lean value stream mapping. The objective was two fold. The first objective was to employ a graphical mechanism for highlighting areas of opportunity for waste reduction and value creation. The second objective was to establish a catalog of detailed process maps to characterize the various processes.

As with Lean Value Stream Mapping, what it is that is flowing through the process must first be determined. It is clear that for this analysis, customer orders are the primary unit of what is flowing through the process. That is not to say that each detailed process map represents the flow as customer orders. Certainly the order processing and engineering aspects of the value chain are represented in terms of orders. However, assembly processes are more simply represented in terms of physical switchgear units. Additionally, the pre-production processes are represented in terms of the components that they produce. When the process maps are assembled at a higher level into a global process map, the appropriate units of flow are converted to provide a consistent representation of the process. For example, before 8DJ orders pass through order processing and engineering into assembly, the orders are organized over a multiple day window and broken into a logical sequence of switchgear to be assembled. At this point in the process, visibility to the order itself is only retained at the level of each piece of switchgear and the associated production schedule date.

One distinction of importance is the notation for total flow time associated with the process. As with lean value stream mapping, a distinction was made between value added time and non-value added time. However, the view value added time in this analysis was quite general given the constraints of project resources. Non-Value added time, represented on the upper lines, indicates time associated with two things: inventory queues and operations that are quite easily discerned as not directly critical in further adding value to the order. These sorts of operations include rework operations, unregulated product testing, unnecessary checks and double checks, etc. For simplicity, value added time, represented on the lower lines, is considered to be the total time to complete any operation excluding any non-value added time. Within pre-production it is clear that a necessary welding process step is comprised of both value and non-value added time. Since theoretical planned job times were used for process flow times, it was not feasible to extract out the inherent non-value added inefficiencies associated with those steps.

One final distinction from lean value stream mapping involved how to represent the various product types that travel the process. The Frankfurt factory offers a very wide range of product combinations. Additionally, any of these products can be customized at the customer's request. Because Frankfurt runs with such a wide range of customization and combinations, it was not completely telling to pick one order and map it through to completion. Many of the unique issues and/or necessary steps that arise with various orders would then be overlooked. For this reason, process maps were represented as general maps that indicate relative frequencies for intermittent process steps. This does tend to aggregate much of the information and, as a result, lose some potential insights. However, given the resource limitations for such a wide scoped project, it was felt that this was the only realistic way to capture the reality of Frankfurt's product and part variability within a single set of process maps. Figure 7 is shown as an example of the mapping exercise.

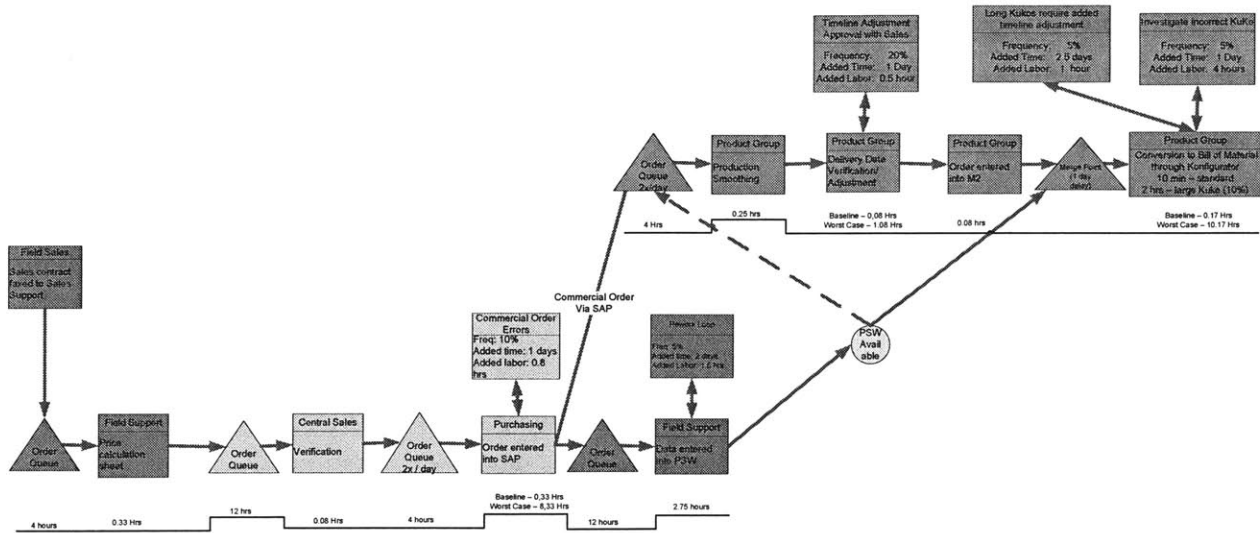


Figure 7 - Process Map for 8DJ product Order Processing. Each shade represents a separate department

Data used to support the afore-mentioned value stream mapping was based on a variety of sources internal to Siemens¹. Primarily, historical data were collected through existing report archives and databases within the company. Additionally, interviews were conducted to gain further insight into the data, as well as shed light on facets of the process flow where historical data did not exist. This combined set of information enabled the completion of phase I as well as defined sources of data to fuel phases II and III. The following is a brief description of the primary sources of data used for this analysis.

SAP: Siemens Frankfurt Factory relies primarily on SAP for all physical inventory management as well as parts production and assembly coordination. For this reason, SAP provided a nearly complete data set for parts production capacity and flow time analysis. One year of historical data ranging from March 2004 to March 2005 was extracted from the SAP data archives and served as a core set of data for numerous analyses. In addition to capacity and flow time analysis of physical part production, this data set gave a foundation to the inventory optimization projects discussed further in Section 8.

¹ In order to maintain confidentiality for Siemens, sensitive data has been modified to mask the true absolute quantities.

M2: As discussed earlier, each 8DH order requires a tremendous amount of custom engineering. An example of this would be the customer specific wiring requirements between voltage sensors, circuit breakers, and the actual medium voltage switch. While the physical order is progressing through the process under the umbrella of SAP coordination, many other necessary tasks that do not represent physical goods must be managed. Examples of these tasks include, wiring schematics, NC programming for custom panels, and testing requirements for each new order. The M2 tool is used by the factory to mesh together performance to schedule management of the SAP controlled activities and the non-physical engineering activities.

Since the M2 acts as a holding place for each order's performance to specific process milestones, historical M2 data was extremely useful in the detailed analysis of product lead time discussed in Section 8.4. One full year of historical data was extracted from M2 history allowing for an analytically sound investigation into the effects of variability on each phase of switchgear production.

Financial Reports:

Summarized financial reports were employed to collect information regarding individual part costs as well as actual part demand over time. This data was critical in driving part level inventory optimization analysis.

Interview: For process areas such as order processing, it was not possible to collect historical data to characterize the documented process flows. This was somewhat problematic considering that many of the activities within the order processing and custom engineering departments contained a high degree of variation. However, if left undefined, answers to the question of variability would be quite inconsistent from interview to interview. For this reason, the interviews were standardized to maintain consistent interpretation of flow times. For a given process step, interviewees were asked the following questions:

- What is the average clock time it takes to complete this step when nothing substantial goes wrong?

- What is the average amount of time you must spend working on this step when nothing substantial goes wrong?
- What percentage of orders requires this step on average?
- When the step takes longer than average to complete, what is the cause?
 - Repeat questions for each assignable cause

By using this format for collection of flow time data, the analysis can isolate relative frequency of occurrence, how impactful the operation is to the flow time, and how much labor is consumed in completing the operation. Additionally, isolating the cause of variability as separate activities, as much as possible, allowed for a more thoughtful analysis of the cumulative effect of variability on the total process.

Although a variety of collection methods were employed to establish baseline flow times for each process step, a few key themes were present through the process. First, the analysis must consider not only the average flow time, but some measure of the variation of flow time in the system as well. Certainly this aspect of the total process flow time is not well understood in the factory. Second, process step level flow time is clearly not additive in the determination of overall value chain flow time. To better represent this point, process flow time was represented in a Gantt chart depicting the flow time critical path. This would prove to be a key insight for the factory in that each product group had a unique critical path. In other words, elimination of flow time from one process might enable shorter lead times for the 8DJ while not impacting 8DH lead times at all. This is important for the Portfolio 2008 effort as well. It is critical to understand that not all flow time reduction efforts would impact the eventual ability to promise customers shorter lead time.

7.6 Insights From Current State analysis

It became clear during phase I of the project that most of the process maps and supporting data were well understood by various employees within the organization. Additionally, it was clear that no one individual or group of individuals had a collective understanding of the entire process and all the interactions of inventory and information therein. Department managers were highly tuned to the detailed activities of their department. Processing capacity, inventory costs, and

flow times were all well optimized at the department level. But at the edges of the departments, process characteristics were not well understood and inter-departmental communication was less fluid. A senior executive at Toyota once summed up the typical German firm by saying, “Who I really fear as competitors are the Germans, if they ever learn how to talk to each other.”^{vi}

Tremendous opportunity for improvement exists where inventory and information jump the departmental divide. Two examples of these potential opportunities are discussed next. The first deals with the flow of order information. The second deals with the flow of physical goods through the assembly processes.

Flow of information

Chinese sales account for a sizeable and rapidly growing part of Frankfurt’s business. When an 8DH product is ordered from Chinese customers, the field sales representative captures the commercial order information and triggers support specialists to calculate a final price for the order. All of this work takes only 20 minutes time. The order is then sent via email to the central office in Germany where it sits in queue. The time in queue is a combination of delays due to periodic queue checks (people don’t continuously inspect their email inbox) and the 8 hour time zone difference that creates a frequent overnight delay (neither office runs continuously). The order is then inspected for accuracy and entered into the SAP system. Finally the order is sent back to China for engineering work through the regional Center of Competence. This regional engineering activity was established to create fewer cultural boundaries between Siemens and the customer with regard to detailed technical specifications. Once this engineering work is done, the order is sent again back to Germany for production.

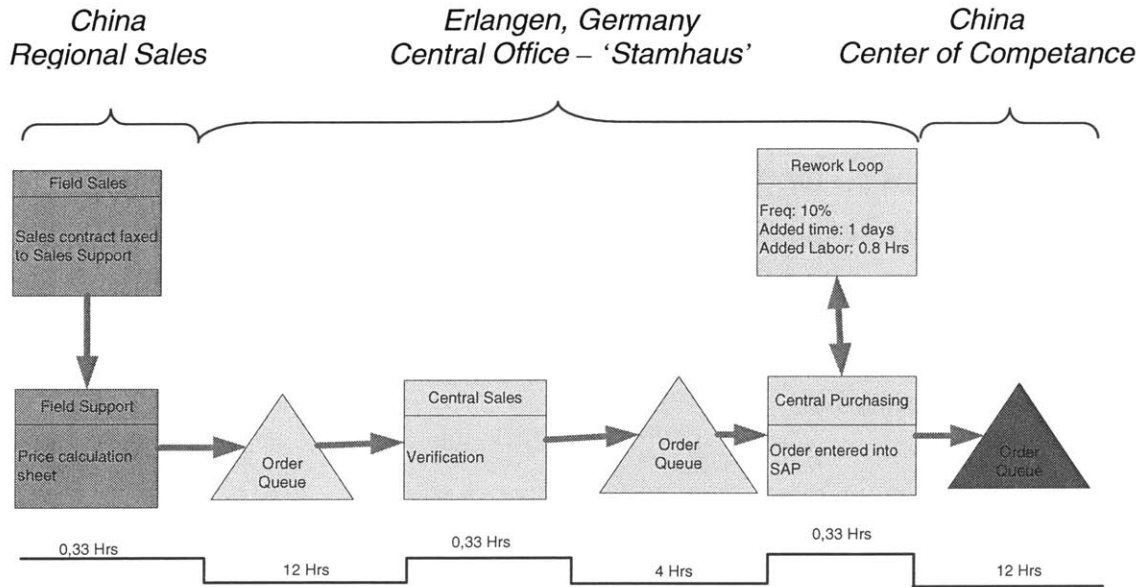


Figure 8 - Order Processing for all 8DH orders captured in China

From this scenario, it is clear that the only value added to the process in the German Sales office is that of verification and data entry. So over 24 hours of additional lead time for this product is associated with a desire by the German sales office to check the work of the Chinese office before any further work could be done. Additionally, there is a sentiment that the regional offices do not have the skills to establish the order in SAP. When viewed department by department, each department is doing an effective job of processing work as it fits within their scope. However, the number of needless and costly exchanges indicates an opportunity for improved inter-departmental coordination.

Flow of product

As described above, the central sub-assembly of the switch gear is the corepart. Once an order is released for assembly, the corepart is first to be produced. This corepart is filled with SF6 gas and then sent on to the final assembly. Figure 9 depicts the last steps of corepart assembly and the first steps of final assembly. Each department is managed quite efficiently and has been the focus of numerous productivity improvements over the last decade. However, it is interesting to note the redundant buffers that connect the two departments. On the core part side, a small one hour buffer of production is kept to protect their own departmental reputation for consistent

downstream feeds. As they see it, any downtime to the laser welding machines or gas filling machines would damage their departmental reputation. This buffer then directly feeds into the final assembly buffer. The final assembly buffer is kept to protect their own interests from the upstream supplier, corepart assembly. One could argue that the only reason buffers are not combined or pooled rests in the organizational structure of the process.

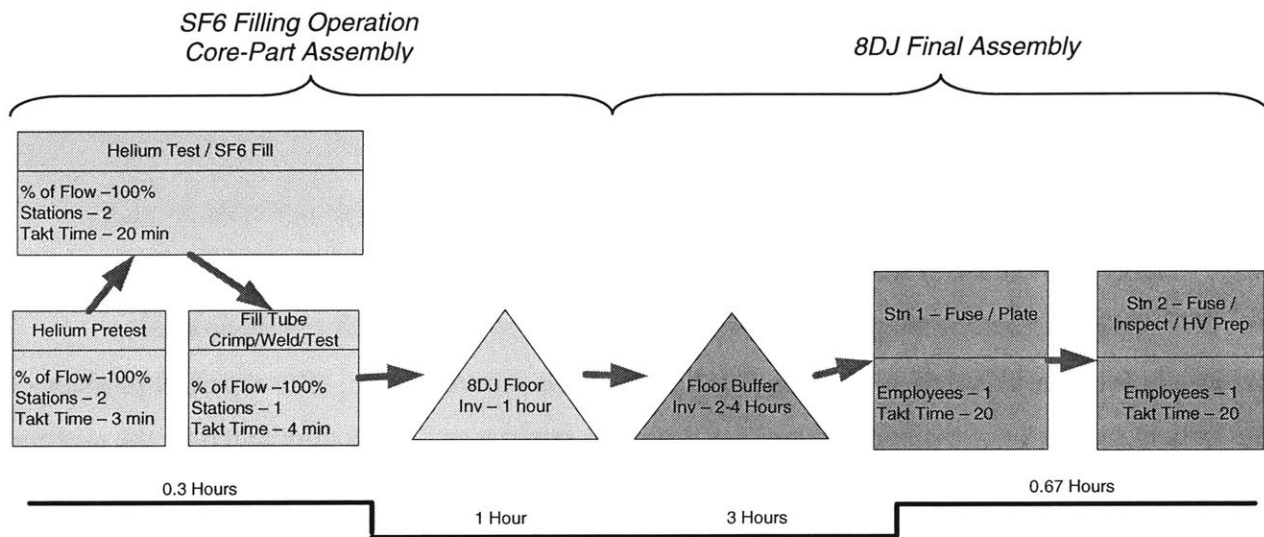


Figure 9 - 8DJ product transition from Core-Part assembly to Final Assembly

Another example of Frankfurt’s attempt to buffer the impacts of one department on another is the parts warehouse. This warehouse allows the pre-production and external vendor batching decisions to be independent of assembly needs, and acts as a massive communication divide between departments. On the one hand, it has created an opportunity for assembly to make substantial productivity gains through its evolution of lean assembly without impacting the upstream operations. On the other hand, not incorporating these upstream operations has limited the gains at the overall factory level while, at the same time, creating an increasingly larger divide between the philosophy of assembly and the philosophy of part production.

Another discovery from the process mapping exercise of phase I was the prevalence of rework that exists throughout the flow of a switchgear order. Most noticeably was the time, both in labor and total flow time, which is taken addressing errors as they occur throughout the flow.

This can again be traced back to incentives on the part of individual departments to maximize their own operation with less regard for the good of the entire system. Take, for example, the sales capture process. Regional sales people have little incentive to ensure that every detail of the commercial order is captured correctly. They know that the central sales office as well as the Frankfurt order processing departments will discover any errors that they make. In fact, regional sales can actually demonstrate increased efficiency if the job is done with decreasing regard for quality. This is predicated on the inability of Siemens to trace these errors back to the root cause and, in turn, penalize them for the error. As errors are found later in the process, they become more costly to resolve. This resulting insight formed the foundation of several recommended projects to eliminate these errors before they occur.

Insights were also taken from the overall review of lead time for the 8DJ and 8DH products. Most notably, the critical path for customer lead time was different for 8DJ and 8DH products. For 8DJ products, the critical path was largely dominated by lead time for parts ordered externally for a specific order. Section 8.4 discusses this in more depth. For the 8DH product, the critical path did not include vendor lead time, but rather was largely dominated by the custom engineering processes required for the circuit breaker products. This was a useful take-away for Siemens because it eliminated the magic bullet mentality that many held within the company. It focused their attention on fully understanding the value of process content and that process content value varied widely. Project valuation will be discussed fully in Section 8.

8 Project Valuation

In order to convert the potential opportunities found while mapping the switchgear process into incontrovertible economic evidence, it was necessary to convert tangible project results into common monetary units. A list of internal valuations was created based on actual and estimated operating costs and revenue opportunities, which were otherwise intangible, not easily attainable or disagreed upon in the factory. These internal valuations include lead time value, employee labor costs, inventory carrying cost etc. Developing and building consensus for these valuations was the critical first step to creating economic incentives in the factory to justify change and create a market where intelligently determined change could organically flourish.

8.1 Opportunity Analysis

During the process mapping exercise, significant inventories throughout the factory were noted. These areas became an obvious area of opportunity as improvement plans for the facility were developed. The most glaring inventory in the factory is certainly the vast central warehouse that divides the operation between pre-production and final assembly. As explained previously in Chapter 7, Frankfurt is essentially two separate factories decoupled by the central warehouse.

As discussed in Section 7.2, two different Kanban systems govern the movement of materials in the factory. Most parts utilize Umlagerung (through warehouse) Kanban, which involves the assembly line pulling materials from warehouse inventory. In-turn, the warehouse is replenished by pre-production through orders of predetermined size, which are triggered when stock levels reach a predefined reorder point as defined in SAP. This allows pre-production order sizes to be decoupled from usable volumes on the assembly line. Savings can be offset or eliminated by increased handling costs and inventory holding costs. Eigenfertigung (literally self-made) Kanban materials are sent around the warehouse and arrive directly on the assembly line. Externally manufactured parts are not part of any kanban system and are handled by a group of material coordinators (Disponenten) and through Siemens MRP system.

There are two major potential areas of opportunity in factories operating as outlined in the brief high-level description provided above. First, converting parts from Umlagerung to Eigenfertigung Kanban reduces inventory and eliminates unnecessary handling. These savings are often coupled with offsetting costs, such as increased setup time and increased space

requirements alongside the assembly line. This effort is fundamental to the principles of Lean Manufacturing, as it provides more space, more free cash flow and more connectivity in the value chain while using less inventory, fewer resources and lowering lead times. An analysis was completed on a part-by-part basis and will be explored in-depth in Section 8.2 below. Second, a full exploration of current inventory management practices could lead to an overall reduction of inventories and properly balance the risk of stockout with the cost of holding inventory. This project will also be explored in full detail in Section 8.3 below.

A thorough analytical consideration of the approaches outlined above, requires the valuation of several variable cost factors including holding cost, handling cost and setup costs. Further, less tangible considerations such as labor and capacity utilization must also be considered. These are often considered separately since they usually behave in a non-linear manner and are not discretely valued.

8.2 Costs of Machine Setup and Inventory Handling

Setup and handling costs should be relatively simple to determine, though they were not widely agreed upon within the factory. Setup labor costs include both the cost of employing personnel as well as the number of hours spent on machine setup. Employee wages are often used, but this does not capture the full cost of employing personnel. The United States Department of Labor defines compensation as “payroll plus supplemental payments, is a measure of the cost to the employer of securing the services of labor. Payroll includes salaries, wages, commissions, dismissal pay, bonuses, vacation and sick leave pay, and compensation in kind.”^{vii} In addition, the variable portions of overhead costs for managing these benefits (such as human resources) and supporting the employee should also be included since they reflect the cost of employing that person. The true cost of labor is typically higher than the base wage by a factor of 2 to 2.5 (the cost a company would bill-out and employee, not the employees wage alone and can vary widely by industry and company).

In most operations employee costs are well understood, while setup times are more anomalous. In Frankfurt, setup times were studied to an exacting degree, documented and even included in the labor contract. However, the cost of the personnel conducting the machine setups and material handling was not widely agreed upon. Initial estimates for this relatively simple cost

factor varied widely with the highest estimates being double the smallest. This inconsistency on this relatively simple matter clearly illustrated a need for a table of internal valuations to enable managers to make intelligent decisions consistently throughout the organization.

After gaining consensus on a labor rate for the Frankfurt factory, this valuation was applied in two main arenas. First, labor valuation was used for projects that resulted in the elimination of excess labor and wasted handling. These opportunities were identified in three main locations; entry into the warehouse, withdrawal from the warehouse and between areas of managerial responsibility. The second use of labor valuations involved labor valuation for machine setup times. These situations often balance the benefits of reduced batch size with the increased costs resulting from increasing the number of setups.

8.2.1 Project Application – Kanban Conversion

One example that incorporates both of these areas involves the conversion of Umlagerung (Indirect) Kanban to Eigenfertigung (Direct) Kanban. This *inventory optimization project* was selected as one of the three projects to be implemented during the LFM internship. Figure 10 represents the basic structure of the factory and the basic flow of parts from pre-production to final assembly.

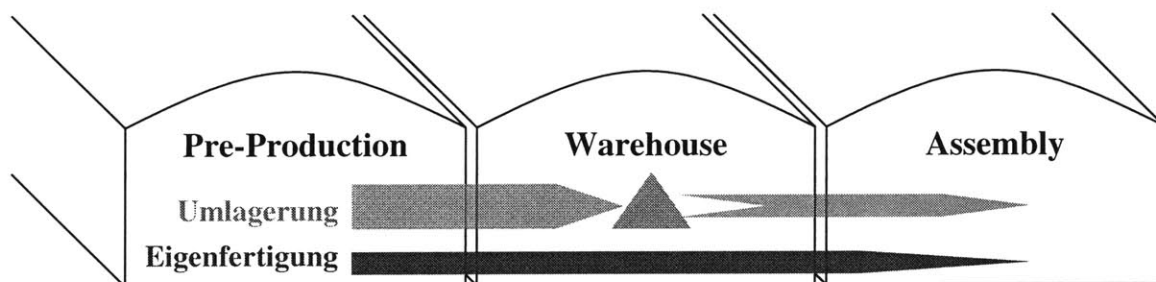


Figure 10 - Factory Kanban Flow

As previously described, U-Kanban parts are moved into the warehouse and later taken to the assembly line. Using the warehouse as a buffer allows both a very short delivery time to the assembly line (about 1 day on average) and flexibility in batch size. More than 99% of parts follow the path of Umlagerung Kanban parts (includes make-to-stock parts as described in section 7.2 above) and are typically large batches as they enter the warehouse. These large batches are later removed from the warehouse in quantities that are appropriate for Final

Assembly. This can require further part sorting, though parts usually stay in one of 17 standard box-types throughout the process. Eigenfertigung Kanban parts, which are taken directly to the assembly line, currently account for less than 1% of pre-production part output. Use of this direct kanban system eliminates unnecessary handling at the warehouse, but also comes with the cost of longer delivery lead times and the need for manageable batches. Though both kanban systems are arguably 'pull systems', U-Kanban fails to capture many of the values that these systems are designed to capture. Per Hopp and Spearman, the most frequently cited benefits of pull systems are:²

- *Reduced WIP and Cycle Time* – from directly limiting WIP to specified levels
- *Smoother Production Flow* – through WIP level dampening
- *Improved Quality* – due to pressures on the system to operate under constraints
- *Reduced Cost* – due to increased stresses on the system

Of these four, U-Kanban, as implemented in Frankfurt, generates only smoother production flow. Final assembly can reliably get parts whenever they need them and pre-production delivery dates for replenishing the warehouse are rather loose due to the buffer volume therein. The buffer volume within this central warehouse symbolizes high levels of WIP (negating the 1st item on the list above), while removing stress on the system (thus negating the 3rd and 4th items). E-Kanban however, would remove large amounts of WIP, eliminate non value-added handling from the system and increase stress on delivery times, part quality and pre-production efficiency.

From the onset of this project, it was clear that the warehouse was a burden on the factory and a major drag on factory operations. However, employees at Siemens had lived with this warehouse very closely and had grown to rely on the comfort of the huge buffer. While dividing their operations with a massive warehouse may be comfortable, moving operations toward leaner manufacturing seldom is. Converting indirect kanban to direct kanban is an obvious way to achieve factory leanness. In fact, Siemens management had generally backed this kanban conversion philosophy. However, philosophy alone doesn't provide a methodology or

² Hopp, W. J., M. L. Spearman. 2004. *To Pull or Not to Pull: What is the Question?*. Manufacturing & Service Operations Management Vol. 6, No. 2, Spring 2004, pp. 133-148

framework for converting these parts or implicitly provide strong impetus for the change. Further, an absolute philosophy would ignore that the warehouse may be an appropriate solution for some parts. A rigorous analysis was required to determine a prioritization for converting parts and an overall idea about how important it was to pursue this project. At the conclusion of the analysis, management greatly increased pressure on factory managers to implement their previously stalled efforts. This struggle between the appropriateness of following pure lean philosophy versus analytical methods is further explored in Chapter 9 below.

Having determined the need for analytic evaluation of the kanban conversion project, it was clear that a valuation of the cost for using the warehouse was required. In order to develop this valuation, financial data from the warehouse cost center was analyzed. All direct variable costs were extracted and prorated for the percentage of internal parts (versus external parts) stored there. The variable portion of transport costs to and from the warehouse was added and the total was conservatively reduced to assume that 70% of these costs could be recoverable (as determined in consultation with the factory operations manager). This total cost was then divided by the number of orders entering the warehouse. This methodology was not a perfect calculation of the true cost of each order since parts are inherently different, different box types are harder to store/handle and batch sizes can vary dramatically. That said, this valuation provided a good starting point and a reasonable estimate from which a list of nearly 5000 parts could be analyzed uniformly. It was estimated that the average order of parts entering the warehouse cost between 5 and 25 Euro/Order (See Figure 11 below - Actual number is confidential). While this value does not seem extremely high at first glance, when considering that nearly 5000 parts enter the warehouse 10 to 15 times throughout a year on average, the resultant costs are very significant and could noticeably impact on the bottom line.

Warehouse Annual Direct Costs	1 to 3 M
% of Warehouse for Internal Parts	+/- 60%
Internal Orders per year	50,000 to 60,000
Warehousing Cost per Order	7 to 30
Internal Transport Ann. Direct Costs Related to WH-Line moves	20,000 to 70,000
Warehouse Transport Costs per Order	1
% of Costs that are Variable (recoverable)	70%
Total Cost Savings for Bypassing Warehouse	5 to 25

(All amounts in Euros, numbers masked or given as ranges for confidentiality)

Figure 11 - Warehouse Cost Analysis

With these valuations of labor and warehouse throughput, the tradeoff among eliminating warehouse costs, increasing setups and inventory level changes could be explored in detail. Optimal batch sizes and the total annual incremental cost (holding, setup and warehousing) were calculated for each of the 4500 parts manufactured in pre-production. These costs were recalculated based on the assumption that the part would be converted to an Eigenfertigung Kanban scheme. A key initial assumption was required to hold production frequency to an acceptable level for the factory. In consultation with pre-production and factory management, we decided that a batch of any particular part should not be produced more frequently than once per week. This assumption provided a reasonable limit for decreasing batch size to start, though would later be refined to reflect the part lead time. Comparing the total annual incremental cost for the two kanban systems provided the estimated savings (positive or negative) if each part were converted to the direct kanban system. (See Appendix 1 to explore the details of this analysis)

Once arriving at a cost savings for converting parts, many other considerations had to be explored to ensure the part was viable for direct kanban. One of the major arguments in the factory against Eigenfertigung kanban was the amount of space required on the assembly line. Line managers essentially refuse to carry more than 2 boxes of parts along the line, as currently required by Umlagerung Kanban and the make-to-stock systems. Through the analysis it was found that 78% of parts could be stored on the assembly line in only 2 boxes (another 10% would require 3 boxes), thus proving the resistance misguided. Another major cause of angst for the production line managers involved the reliability of pre-production to deliver orders in a

timely manner. Deliveries coming from stock in the warehouse are usually delivered during the following work day with high consistency, however orders from pre-production take from 2.5 to 9.5 days on average depending on the part (mean of around 5 days) and involve greater variability (average standard deviation greater than 1 day). In order to ensure that these parts can be reliably delivered before a stockout occurs, delivery time as well as demand variability must be considered. Likelihood of stockout became an important criterion for prioritizing parts for conversion. Parts with a worst case lead time (here the mean plus three standard deviations was used) greater than the depletion time of 1 box (capacity divided by peak season daily demand) were considered unfit for the first pass at kanban conversion.

Overall, 54% of parts fit in 2 boxes, met the lead time criterion and had positive savings! These annual savings would total over 300,000 Euro (US\$400,000). It was clear that this project was important to the factory and approval was fast-tracked through management. The problem remained of how to achieve lasting implementation. Though the project offered significant savings, improper implementation could have dire consequences to a factory that is currently reliant on large inventory buffers. The part conversions must be implemented in small groups at the level of each product group manager and his material managers. In order to provide more familiarity with these methodologies to these key decision makers, we provided a tool and training. The spreadsheet tool (see Appendix 1) is an important piece of bridging the gap between a one-time analysis and providing the factory personnel a way to make living decisions and learn to use these methodologies on a daily basis.

8.3 Cost of Holding Inventory

Throughout the factory, with almost perfect consistency, people use 7% as the cost of capital *and* holding cost. However, several costs were not being rolled into this value directly, including scrap and variable overhead charges.

Scrap rates for inventory at the Frankfurt factory added nearly 3% to the cost of capital due to the high incidence of part redesign. When parts are redesigned, old inventory becomes obsolete and is scrapped. When new products are rolled out such as the new 2008 product portfolio, greatly increased amounts of scrap are generated. This was found to be a frequent occurrence in Frankfurt. To determine the appropriate increase to the cost of holding inventory associated with

scrapped parts, total scrap costs and total part costs were extracted from FY2005 financial reports. The scrap ratio is defined as follows:

$$\text{ScrapRate} = \frac{\text{ScrapCost}}{\text{TotalPartsCost}}$$

Where,

- *ScrapCost* = total cost (Euro) of all scrap parts in 2005
- *TotalPartsCost* = total cost (Euro) of all parts produced in 2005

This calculation yielded a scrap rate of 3.2%. However, a routine review with factory management revealed that in April of 2005 the 8DJ product line was revised and a sizeable number of standard parts were made obsolete. In response to this, the analysis was broken into monthly increments to better understand the potential of April as an outlier. Removing April data from the calculation, the scrap rate dropped only slightly to 2.8%.

The result of the analysis for scrap rate and other minor factors brought the true cost of holding inventory to approximately 10%. Holding cost, while not as forceful a driver as lead time (see section 8.4 below), is a significant source of impetus for completing improvement projects at the Frankfurt plant. Though the factory was very consistent in their use of 7% as a holding cost throughout the factory, this number was somewhat inaccurate. Accuracy and consistency are both extremely important factors for internal valuations so that decisions made are both correct and consistent through the organization.

8.3.1 Project Application – Safety Stock Evaluation

The results of the holding cost valuations were critical for analyzing Siemens' current levels of safety stock. Though the results are applicable throughout the factory, this analysis concentrated on parts manufactured in Frankfurt and held in the central warehouse. Safety stock for these parts is managed through Siemens' SAP system. They have chosen a static method for managing inventories and strongly believe that the dynamic methods (i.e. using moving averages of recent historic data) in SAP are incompatible with their seasonally varying demand. Siemens demand does reflect a slight seasonal demand, which could be handled in SAP fairly accurately. A larger problem for the dynamic method is that customer orders tend to group similar or

identical products in their orders. This demand clustering, is directly reflected at the individual part level within each product group and can make moving averages highly unreliable. For example, a Swedish customer ordering 50 panels would tend to order a particular model with parts particular to their country or regulatory environment. This clustering along with slight seasonality influenced Siemens to use a static inventory management system within SAP.

The static inventory levels were very consistent across large groups of parts. Inventory levels for almost every part are set in one of two ways. For frequently utilized parts, a minimum of 10 days of parts (based on current demand) are maintained in stock. The second method involves a specific minimum quantity. These minimum levels are not the reorder points of classic inventory management models, but rather a minimum level that the system actively targets. The nature of this business involves long product delivery times on the order of 4-10 weeks and short internal part delivery times on the order of 1-5 days. This allows SAP to determine future part requirements to a high level of precision and results in new part orders consistently arriving when inventory levels reach the targeted quantity. By this methodology, on time part arrival should be 50% and frequency of stockouts should be extremely low. (Please see the end of Section 7.2 above for more detail on how SAP manages stocks)

The frequency of use in SAP of 10 days or 100 parts as minimum stock targets, indicates a somewhat arbitrary process and is inconsistent with a well thought out analytical approach to inventory management. Clearly there exists some value in adding a more rigorous approach to determining these base stock levels. The *Safety Stock* project quantifies these savings and recommends an improved course of action for managing factory inventories.

Initial calculations, using the formula below, suggested that average inventories in the factory were about 50% higher than required.

$$SS = z * \sigma_{DD} \sqrt{\mu_{LT}} \quad ^3$$

Where; z = safety factor, LT = lead time, DD = Daily Demand, μ = average and σ = standard deviation

A 99.99% service level was used here as indication of a stockout event at the part level, which would result in an estimated 7 stock out events throughout the year for all parts (see table below).

³ Designing & Managing the Supply Chain; David Simchi Levi, Philip Kaminsky, Edith Simchi-Levi

This relatively high service level is required at the part level since there are so many parts that go into each end-product and any one of them could cause problems at the assembly line. Most factory assembly lines currently experience part stockouts, or near-stockouts on a weekly basis. They routinely handle these problems by expediting part orders, which can usually be turned around within a day or two from pre-production. A table of results for average expected stockouts that affect assembly lines throughout the factory can be seen below along with estimated savings as generated during final stages of this analysis. The annual expected number of stockouts was calculated based on the average number of part types needed for a finished product and the corresponding service level/safety factor applied at the part level. The analysis assumes part demand is normally distributed and independent among parts, which is reasonable though not perfect since equipment failure and capacity constraints in pre-production would affect a great number of parts during each event. This table can be used by management to set a proper service level target and aid the decision of trading off safety stock savings (based on 10% holding cost) for limiting the number of stockouts.

Service Level	SS Cost Savings	Estimated Stock Out Events	z Factor
99.500%	63500	339	2.58
99.900%	55700	68	3.09
99.930%	54100	47	3.19
99.960%	51700	27	3.35
99.990%	46200	6.8	3.72
99.999%	37900	1.0	4.26

Figure 12 - Stockout Consideration

As can be seen in Figure 13 below, there are decreasing returns for eliminating stockouts and a distinctive inflection point, which should aid in this managerial decision.

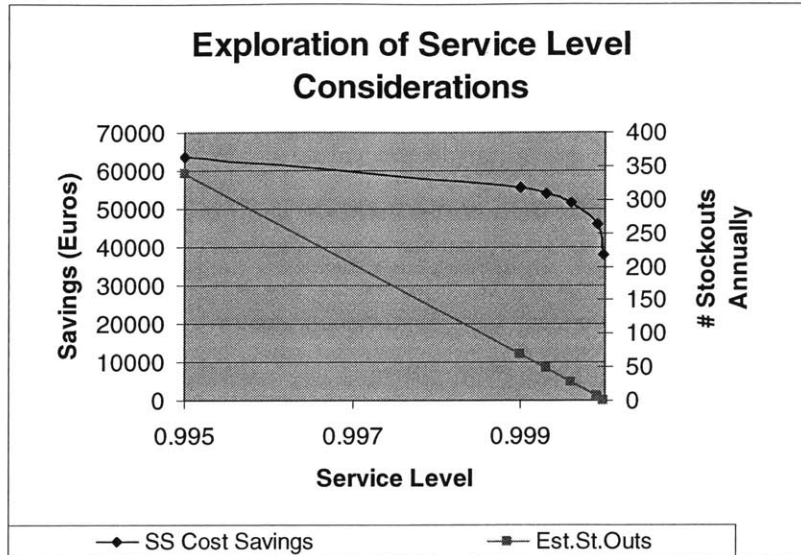


Figure 13 - Exploration of Service Level

Since there was such a strong indication of potential savings, a more detailed analysis was initiated to factor in variation of demand, variation of part lead time to the assembly line, particular intricacies of the parts and pre-production areas and other fixed requirement factors such as the ‘chunkiness’ of part production (i.e. real and perceived restrictions on batch size). When calculating safety stock with variable lead time and demand, the following equation was used:

$$SS = z * \sqrt{\mu_{LT}^2 * \sigma_{DD}^2 + \mu_{DD}^2 * \sigma_{LT}^2} \quad 4$$

One interesting result found in exploring the Frankfurt factory, is that demand for most parts is accurately known in SAP before part production must begin (Lead Times < Delivery Date – Order Date). In these cases the actual net lead time is negative, though for the sake of safety stock calculation cannot be less than zero. For example, it takes 3 days on average to produce a particular bent steel part, but demand is known with near-certainty weeks in advance. Thus σ_{DD} is set to zero and leaves:

$$SS = z * \sqrt{\mu_{DD}^2 * \sigma_{LT}^2} = z * \mu_{DD} * \sigma_{LT}$$

Which is just the portion of safety stock that is associated with variable lead time; the z percentile of expected lead time multiplied by the average expected demand each day.

This is an interesting result and speaks in part to the value of MRP systems – when you can set and fix the master assembly schedule; then component demand is known with near-certainty and this source of variation is eliminated. In application however each product has differing amounts of “SAP foresight”, some parts have very long lead times and/or very lumpy demand. Thus the master schedule cannot be fixed far enough in advance to cover these lead times and the MRP system does not completely eliminate variation of daily demand. The mean net lead time would have to be well below zero such that an unconstrained distribution would not have any substantial volume above zero (and thus creating potential for stockouts). For this project, these effects were ignored since management was unwilling to rely on SAP in this manner, in-part for the reasons outlined above. The benefit from ERP software is limited to acting as an extra buffer supporting on-time part delivery. One additional note of interest is that projects resulting in customer lead time reductions (discussed in Section 8.4) could actually increase the amount of safety stock if SAP foresight is considered (since previously negative lead times could suddenly become positive).

Another major factor for analyzing proper safety stock levels is management’s strategy for dealing with seasonal demand and tight capacity restrictions in some pre-production areas. According to factory management, resin, which is a highly uncontrolled and specialized process, had to be removed from the analysis for this reason. The level production of resin parts in Frankfurt builds inventory during the year for the peak summer season. Aluminum parts were also removed because outside vendors were involved, lead times were long and management was opposed to tweaking this critical piece of their supply chain.

The remaining parts were analyzed using the formulations shown above, providing a snapshot analysis of savings for reevaluating safety stock levels. The analysis indicated that inventory levels could be reduced by 45% (462,000€), which would result in annual savings of around 46,200€. This result utilized some estimates of variation based on the volume of product demand. Demand levels were categorized into groups of high, medium, low volume and ‘rare’ with standard deviations taking on various multiples of daily demand. For example, typical high

⁴ Designing & Managing the Supply Chain; David Simchi Levi, Philip Kaminsky, Edith Simchi-Levi

volume parts were found to have standard deviations approximately equal to 40% of daily demand, while low volume parts tended to be closer to 4 times daily demand.

Perhaps the most beneficial result of this work is the training of staff on the methodologies used and enabling material managers at the base levels of the organization to look at their decisions analytically. As touched upon earlier, experience is important in the role of the material manager and most inventory level decisions are made based on either experienced estimates by these personnel, or as reactions to problems experienced in the factory. The tool provided can help to correct both of these problems. First, analytic support is provided to help make sound decisions on a day-to-day basis while still incorporating the intrinsic knowledge and experience of these employees. Second, reaction to problems on the factory floor has the unidirectional effect to increase overall inventory levels. By eliminating these one-time changes and objectively analyzing the available data, areas for improvement can be spotted and further considered.

8.4 Lead Time Valuation

Throughout the life of Project Portfolio 2008, managers have struggled with the importance of customer lead time. While the ability to deliver product to a customer in less time intuitively has some value, quantifying this benefit has been a significant challenge. Without understanding the value of lead time reductions, projects with this result stand in limbo without economic justification or clear political backing to reach fruition.

In Siemens PTD, product lead time is discussed almost exclusively as a deadline. The idea that a particular switchgear product must be offered within one specific lead time for all customers is not a market driven fact and provides no incentive to reach beyond this somewhat arbitrary mark. In practice, the market research used to set this mark is relatively thin and is often unscientifically modified to meet existing capabilities, rather than market forces. In contrast, establishing the value of lead time for particular product groups enables managers and executives to make intelligent decisions and evaluate individual projects on their particular merits.

Since material management systems vary across areas of the factory, analysis was separated into three major categories. In each of these areas (pre-production activities, order processing activities and assembly activities) a reduction of processing time produces varying outcomes. Most activities in pre-production are feeders into inventory buffers and thus affect safety stock,

but do not affect customer lead times under the current operating structure. Activities in order processing affect customer satisfaction directly, but only affect customer lead time after a contract is signed. All assembly work and queuing occurring after the contract is signed directly affect customer lead time. It is this last area that contains the most opportunity and thus the area on which much of the analysis is focused. Many potential opportunities reduced customer lead time alone, while others were offset by other project costs.

8.4.1 Project Application – Laser Welding Production Planning

One example of such a project idea where inventory and lead time savings were offset by increases in capital and setup labor costs, concerns several massive laser welding machines. Laser welders are responsible for the very critical step of welding together the hermetically sealed core part housings. In an example of classic mass manufacturing mentality, a few huge laser welding machines requiring long setups are operated with the goal of maximizing run time. To accomplish this goal, large batches are required. Orders are grouped each morning in order to minimize setups, resulting in a long queue of orders ahead of this work area. The assembly processes immediately following laser welding prefer to sequence their work by delivery date so that different parts of an order arrive together at shipping and to ensure that customer dates are met. The result of this reordering is a 24 hour queue of partially finished core parts between laser weld and core part assembly on a gigantic 5 level pallet rack. Additionally, the non-value added human efforts of palletizing, placing, retrieving and de-palletizing the partially finished core parts are significant.

The project idea revolves around reducing the period over which the laser welding area is optimized (currently daily), resulting in reduction of inventory and customer lead time. Additionally, the wasted movements described above could be eliminated by purchasing additional mechanized assembly wagons (required at the following work station) to hold the parts in the buffer. This caveat produces further incentive to reduce the buffer size, as the capital costs can be quite significant. It is also important to note that reducing setup time or eliminating the need for setups altogether is the preferred solution. In this case, this was not possible during the term of this project, but was emphatically highlighted during manufacturing planning and redesign for the Project Portfolio 2008 effort.

The analysis showed that inventory savings did not offset the increased cost of setups alone, but when the value of lead time reductions are considered the project becomes economically advantageous. Lead time is important here since this process is on the critical path for customer delivery. Final results of this analysis are shown in Figure 14 below. As the size of the laser welding optimization period (batch size) decreases, capital and inventory costs are reduced, while setup costs rise. The existing practice as described above is to sort orders once per day, reducing direct costs to this department, but the minimum cost global solution is to sort orders every 6 hours. A steep rise occurs as the optimization period approaches one-piece flow due to a rapid rise in setup costs. The gentle slope on the right side of the curves is due to lead time reductions only partially offset by slowly increasing setup costs. In this case the project was transferred to the welding manager along with the recommendation to optimize the station over an 8-hour shift (rather than each day) and seek ways to reduce setup time.

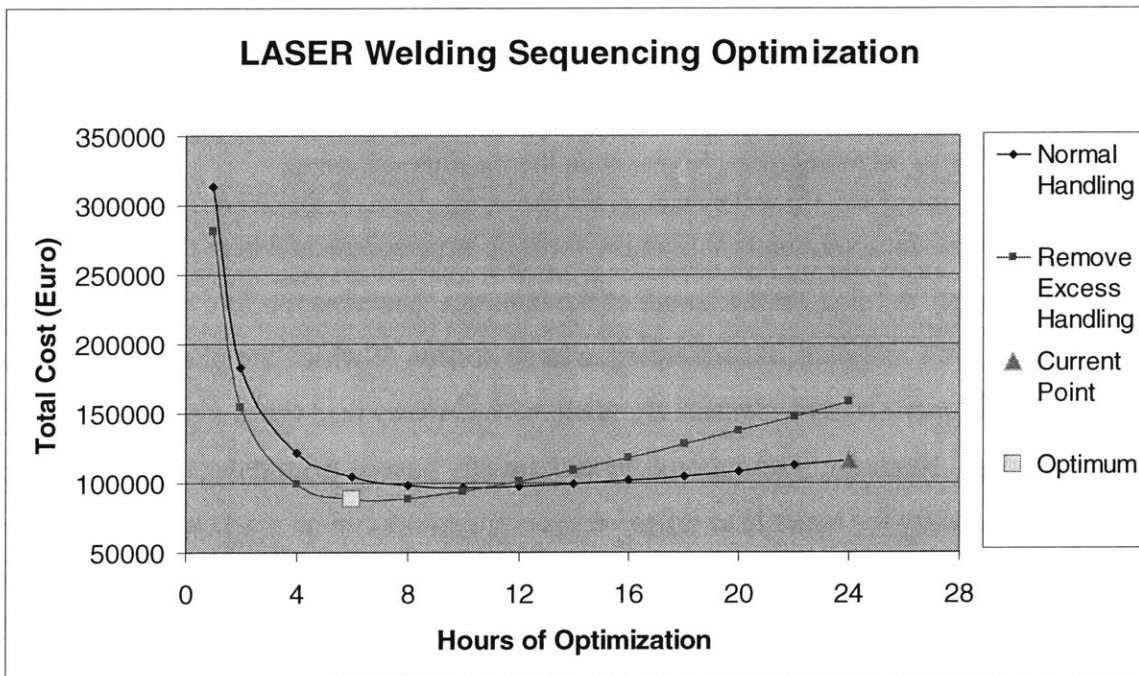


Figure 14 - Laser Welding Sequence Analysis Results

The laser welding sequence illustration shows the importance of lead time valuation to create proper incentives and justification for improvement projects. But, where is the value of lead time derived and how can it be estimated? By providing the customer a faster delivery, the manufacturer should be able to increase units sold and/or the price charged for the units. Thus

value is realized through increased revenues. Additionally, secondary costs and benefits of inventory, labor etc. must be evaluated. Projecting the sales effect of a product change is an incredibly hard task especially when the change has been untested. Establishing agreement within Siemens on even a bare minimum baseline of 1-2% increase in revenue would be enough to fundamentally change the way customer lead time is approached.⁵ The reasoning followed that projects affecting lead time would be very attractive to the business and drive several stalled projects forward. Without specific valuation, incentive to reduce customer lead time was not present and many high value opportunities went unnoticed.

8.4.2 Lead Time in terms of Euro value

In developing the logic behind how customers will react to changes in product lead time, agreement from the head of sales in Siemens' Erlangen, Germany office would be needed. At Siemens, formal authority is extremely important. Success depended on the ability to negotiate and agree on a plausible minimum sales effect with many layers of sales personnel. Starting with the Project Portfolio 2008 resident sales department representative, it was surprising to find his gut-feel estimate to be many times higher than the baseline estimate.

A large portion of product volume is sold in the form of large contracts where the type and date of delivery are clearly defined for the length of the contract. Siemens top five 8DJ customers combine for over 30% of panels manufactured, a large portion of which are planned deliveries. Further, some customer delivery requests are made with delivery lead times much longer than existing lead times. Neither of these groups would directly benefit from reduced lead times. However, the capability for better lead times versus competitors can be marketed to customers and provide some (not quantified here) psychological effect consistent with product quality and overall firm capabilities. Aided by order data, sales personnel estimate the percentage of customer orders where lead time plays an important role in the purchase decision at 70% or more. Historical data suggests that a few large customers comprise a significant portion of sales, while the smallest 83% of customers combine for only 16% of sales.

⁵ Determined in-part through conversations with Professor Graves during a visit to the Frankfurt plant

Considering these factors, the 20% increase in sales seemed possible, but did not provide a bare minimum that everyone could agree upon. Through some negotiation and consideration of sales data, it was determined that 5% was an acceptable minimum increase that could be expected from a 50% reduction in lead time for 8DJ and 8DH. This baseline was agreed upon by other sales representatives and finally by the head of sales himself.

Since this was a baseline estimate, we simplified the approach to say that increased revenues directly translate into increased profits. The assumption here is that profit margins are constant; no economies of scale are realized and no additional value is extracted from the psychological effects described above. While these affects could be estimated (predicted to a rather limited degree of accuracy), the baseline is more than ample to promote reduction of lead time through several current project ideas. The following graph shows how this sales increase was simply translated into the value of 8DJ lead time in Euros per Day. Though this is broken down into daily increments for convenience, we recognized that value will not be realized until Siemens can promise a customer reduced delivery in 1 week increments. Thus, several smaller projects may need to be combined in order to realize value for each lead time reductions.

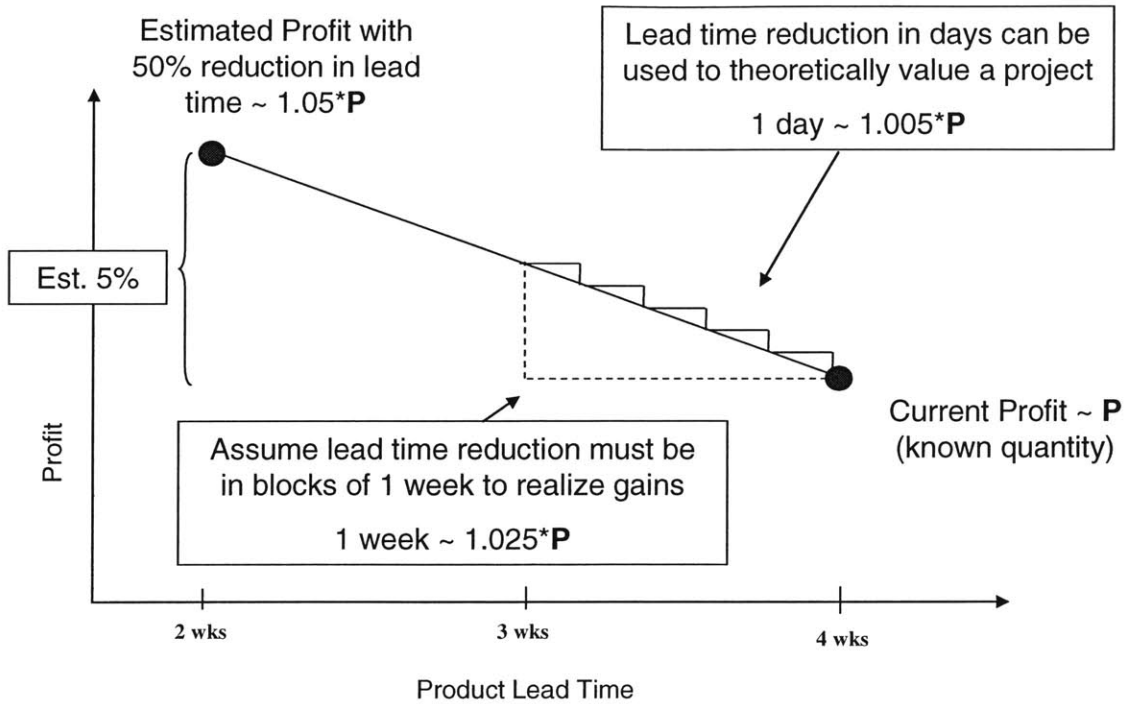


Figure 15 - Lead Time Valuation Breakdown

8.4.3 Project Application – Exact Parts

The project most directly related to lead time actually involves increasing inventory levels; an action that is somewhat incongruent to what most people consider ‘lean’. Most lean programs push the absolute reduction of inventory, rather than recognizing tradeoffs between buffers, of which inventory is only one type. In thinking through the critical path for customer lead time, we imagined the customer’s order traveling through the entire process from order processing through delivery. This was completed for products associated with Projekt Porfolio 2008, as shown in the to-scale timeline below for 8DJ.

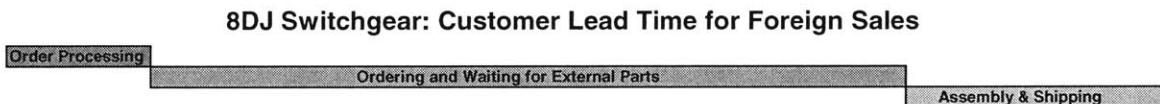


Figure 16 - Average Timeline for 8DJ Process

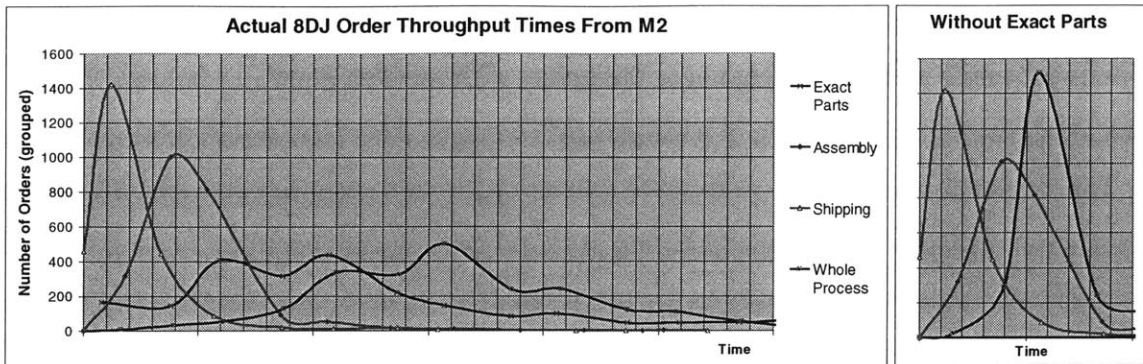


Figure 17 - Actual Times for 8DJ from Frankfurt's M2 Tool

As can be seen above the average customer traveling through the 8DJ process would spend a few days in order processing, which involves a few trips back and forth from the home country to the sales department in Germany. Next, the customer waits around with no interaction for 3 weeks, progresses through assembly for 5 days (including two 24 hour queues and 7 hours of value added time) before finally being wrapped and packed into a truck. The customer spends a total of 4 weeks on this virtual trip with less than 10 hours (2%) of his/her time actively engaged.

The search to find the reasoning behind this central 3-week period of waiting turned up some surprising results. Initial conversations with material planners revealed that almost every order contained “Exacte Teile” or *Exact Parts*, which are purchased specifically for a particular order only after that order had been processed. Further, this individual believed that each order only had one or two exact parts. In effect this would have meant that the factory was holding up assembly of a product for which they had 499 parts in stock, while waiting for delivery of the 500th part. The reason given was not surprising. Since these parts were infrequently ordered, it would cost “too much” to keep them in inventory. The shortsightedness of an individual department deep in the heart of the organization was not surprising; the workers were focused on materials management and did not often consider how their decisions affected customer lead time or the consequent effect on product sales. Considering effects beyond the departmental level; the cost of holding stock for 1 additional part is often much lower compared to the value of reducing delivery times on a few orders by several weeks.

Data showed that only 30% of 8DJ orders contained exact parts. The immediate hypothesis held that delivery of these orders must be much longer than orders not affected by exact parts.

Surprisingly, this was quickly disproved as distribution of customer lead time for orders with exact parts proved to be almost identical to the orders without (See Figure 18 below). Notice the obvious local maximums occurring at multiples of 5 working days (one week) throughout the chart. This is mostly the effect of working to deliver orders to a customer on a specific delivery date (not earlier or later) as determined during order processing and measured in weeks. Since the assembly start date is tied directly to the promised delivery date, it is clear that the 70% of orders not containing exact parts wait for an average of nearly 3 weeks until any work is completed.

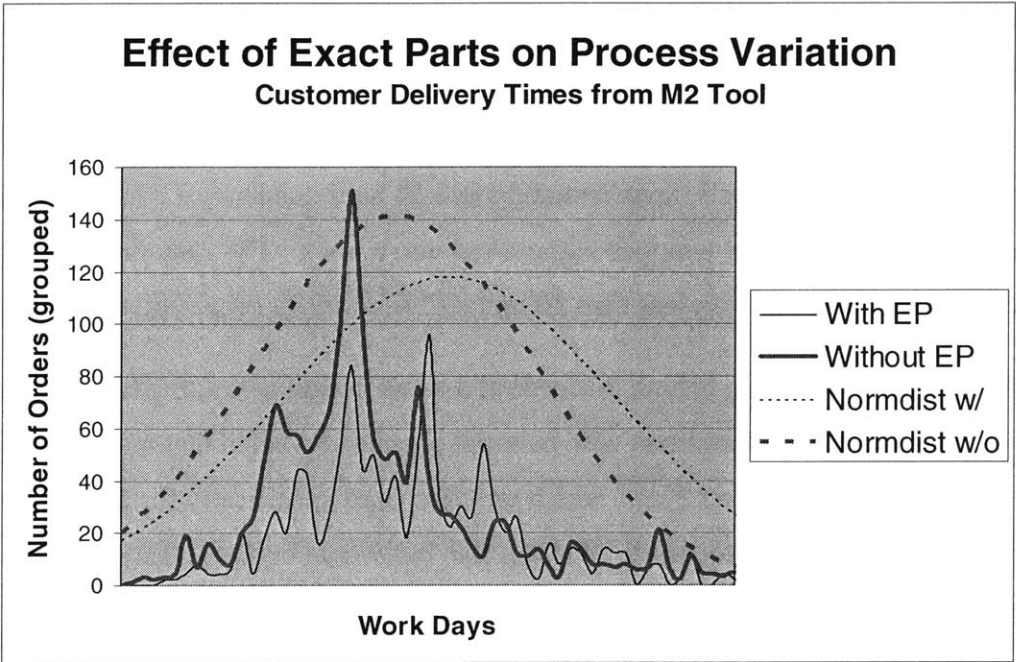


Figure 18 - Process Variation and Exact Parts

If these 7000 non-exact part 8DJ orders were identifiable at the time of ordering and customers were promised a 2-week delivery, a minimum of 350,000 Euro of additional revenue would be captured each year (as estimated by the lead time valuation explanation above).

Implementation for this project focused on finding ways to inform sales personnel and convincing management of the potential of these new ideas. First, sales personnel must be able to differentiate orders with and without exact parts. Siemens is committed to flexibility and offering very customized solutions and so simply eliminating exact parts is not an option. The best solution for providing information to the sales force was found in their existing home-grown

computerized ordering tool. A small list containing the standard selections containing exact parts could be added to the software database. A small modification to the tool would indicate to the sales person that an exact part is present and that a longer lead time is required. This first change is expected to have two significant effects. First, lead times could be immediately cut in half for 70% of current orders. Second, natural selection would decrease use of exact parts as sales personnel entering orders for customers with immediate needs would tend to avoid exact parts orders.

Furthermore, it is possible to further increase the number of orders eligible for shortened delivery times by strategically stocking parts that are currently classified as “exact”. Using data from SAP, including frequency and quantity of order, appropriate stocking levels were calculated for the exact parts. Once the stocking plan was approved by the 8DJ product manager, the most frequently ordered parts were converted into normal stock parts with a minimum inventory level to trigger a restock order. Though increasing inventory seems counter-intuitive and perhaps incongruous to lean thinking, it is an intelligent decision in this case, made possible by understanding the valuations of several factors.

It is also important to note the importance of working with suppliers to shorten lead times for delivery of these parts, which would render the stocking effort unnecessary. Unfortunately, language barriers prevented much work in this particular area during the internships.

8.5 Lead Time Variation

Process variation is another critical factor that must be considered when converting these ideas into actionable, customer valued projects. Most work is thought of and evaluated based on averages, but the amount and frequency of deviation from the mean can be just as important to understand. Throughout the process mapping exercise, employees would state deviations from the standard process, often in the form of rework loops or exceptional items. For instance, one interviewee stated that a particular computer entry process took 20 minutes per order, but took 4 hours for about 10% of orders. This large deviation is important to understand, as it can have a large impact on the flow of orders through the process. Information recorded always included both the amount of time required to complete the added step and the probability that it would be required. In order to promise the customer a reduced lead time, it is especially important to

ensure the product could be delivered within a reasonable degree of accuracy. One example where this reasoning was applied to project analysis is in order processing.

Total order processing times found during the process mapping exercise were consistently lower than the actual throughput durations observed from Frankfurt production data. This was not surprising since the critical path was calculated based on the most likely scenario, which ignored rework loops and other variation from the norm. We recognized that customer promises are not made based on the average throughput time, but rather on a reasonably assured throughput time (say the 98th percentile). To explain how this variability affects customer lead time, please refer to figure 19 below. Average “Best Case” and “Worst Case” (including all rework) Gantt charts were developed along with the probability density function (PDF) “Actual Distribution”, which shows the probability distribution that links two extremes. In the case of 8DJ foreign sales, the best case time for processing an order might be 2.75 days, while the worst case is 6.75 days. By combining the probabilities and resulting delay for each potential event a PDF emerges. In this case, if Siemens chose to promise the customer delivery times based on the 98th percentile, they would allow 4.25 days for this process. By understanding lead time through this example, tangible incentives to reduce lead time by eliminating process variation become apparent. Several projects that removed variation, usually by reducing the likelihood of rework loops or by making processes more robust, were evaluated using this methodology.

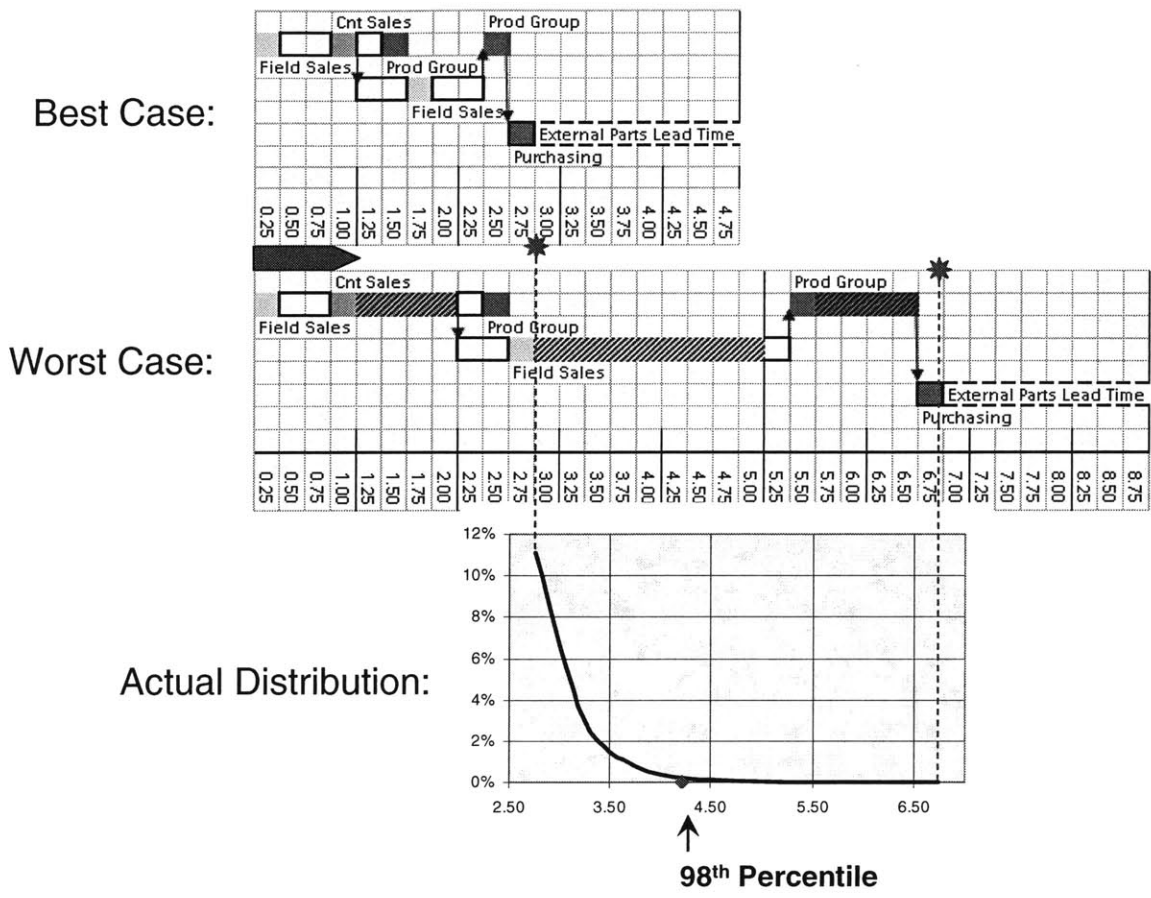


Figure 19 - Process Variation Analysis for 8DJ Foreign Sales Order Processing

This analysis involved error reduction for incoming orders by standardizing the process for handling orders in field locations throughout the world. The method suggested for realizing these sales was a web-based training platform. The training material and standardized processes were already fully developed. Furthermore, Siemens' Communications division provides extensive computer based training (CBT) throughout the corporation. Despite PTD being the only Siemens division that declined participation in the CBT program, the Communications department agreed to host a training module for these purposes. The project was pitched to the head of the related sales department and transferred to that division for implementation.

8.6 Factors Without Discrete Valuation

Other considerations such as labor availability and capital utilization can be both extremely important and extremely complex to evaluate. The German labor market is widely portrayed in the business press as being highly inflexible. Surprisingly, labor at the Frankfurt factory was more flexible compared to union labor in the US. Whole shifts could be reorganized to fit

changing demand conditions, though this was usually conducted on more of a multiple-week basis. An hour banking system ensures that workers are paid for a minimum number of hours in return for schedule flexibility. In this system, management has a high level of control over when an employee reports to and leaves the workplace as demand and internal factory dynamics change.

Whereas labor was rather flexible and largely available, over utilization of capital equipment was a larger concern. Utilization as used here includes only time for setups and for useful work, which is then divided by the available time for the tool (here 24 hours a day for 5 days each week). This helps determine the feasibility of performing increased factory operations provided the current capital structure. The peak demand and available capacity of capital equipment such as laser welding machines, sheet metal bending tools etc. must be well understood to avoid unexpected bottlenecks. These considerations were largely handled by understanding baseline operating capacities and calculating expected changes for any major change proposal. For example, several project suggestions involved reducing batch size, which in turn increased the number of setups and finally reduced tool availability. The results of this waterfall of change were checked to ensure capital utilization did not exceed 80% (as found to be nearing the limit of current capabilities in the factory). This dynamic valuation to capacity limit encroachment formed an iterative process, allowing consideration of factors that are extremely difficult to calculate otherwise.

A capacity planning tool was also generated to provide Siemens the ability to explore how increases in sales volume would affect capital utilization. This tool also explored expectations for capital purchases to handle increased volumes through several different methods. This model will be especially helpful as Siemens looks ahead to the rollout of Portfolio 2008 products, which is expected to be a period of high demand growth and market share expansion.

9 Our Struggle – Analytics versus Lean Philosophy

Over the course of this project analysis the project team has learned a great deal about the way in which a factory can effectively undertake large-scale improvement. The bulk of this thesis leans toward the more heavily analytical approach to evaluating factory improvement. However, the initial phase I of this project was strikingly similar to a lean factory improvement initiative.

First, understand the process and map it out to understand how value is delivered to the customer. Next, identify waste in the process that inhibits value creation or creates waste within the organization. It is at this next step that the two methods diverge. In a philosophically lean approach, the project ideas would be immediately driven to implementation on the principle that waste should be eliminated.

We acknowledge that this is not the first paper to search for the proper balance along the spectrum between pure philosophy and analytic rigor. The explosion of ‘Lean Manufacturing’ programs spurred by management literature attempting to unlock the secrets of the Toyota Production System (TPS) has left incredible confusion in its wake. These programs are often extremely different in their aims and often unrecognizable in comparison with their TPS origin.

Buffers, whether in the form of time, capacity or inventory, are necessary in the production environment due to variability. In recognizing this fact, Hopp and Spearman sum up the problem nicely in defining the object of lean as the elimination of the *costs* of buffering.^{viii}

Given that the goal of a company is to make money, the aim should not be to reduce buffers, but rather to minimize the costs resulting from buffering. In this approach, it was necessary to first explore and understand the internal costs at play in the factory and only then determine the best way to modify operations in the interest of profits (that is *both* cost and revenue). Successful philosophies aimed at dealing with non-obvious waste can be developed only after these factors are well understood.

In a 1991 HBS article, Zipkin speaks at length about the differences between “romantic” philosophical approaches to just in time (JIT) versus more pragmatic and realistic methods.^{ix} He further develops the contrast between philosophical thinkers portraying inventory as inherently evil, while pragmatists recognize it as one form of buffer. Inventory buffers need to be balanced along with other forms of buffers to maximize profit.

In this project, the areas of opportunity were closely scrutinized through a series of detailed valuation techniques to determine the Euro value of the each project. Through this method approximately half of the original project ideas were discarded if financial returns were negative, which is a starkly different result than a lean factory improvement initiative would produce. The following is insights into the pros and cons of each method, concluded with a proposal on how the two should be used in concert with one another.

Lean Philosophy

The real value associated with driving factory improvement under the umbrella of Lean Philosophy is in its agility to respond as ideas are generated. To the extent that every employee in the organization understands the direction, it is a trivial matter to justify the importance of undertaking a project that eliminates waste from the system. There is likely no faster and more efficient way to achieve an end state vision than through the total acceptance and understanding of a well designed lean program. However, this method relies on the acceptance and understanding of employees at all levels of the organization. If skeptical managers are unwilling to accept the philosophy at face value, the program faces the risk of halting or increasing costs. Take, as an example, the relationship between assembly and pre-production in the Frankfurt factory. Lean philosophy has served assembly well in its drive to be more efficient. But as the boundary of lean extended beyond the warehouse and into pre-production, managers pushed back. Pre-production managers did not want to drive to smaller, more frequent batches without knowing full well the value that this added to the company and ensuring that they could reliably meet the new constraints. This is where the lean philosophy, as implemented at Siemens, ended.

Analytical Approach

In the example above, pre-production was willing to do the right thing for the company, they just were not willing to do it without proof. This is where the analytical approach outlined in this thesis becomes invaluable. Consider this approach as creating the necessary activation energy to get the lean philosophy moving again. Of course, the inherent downside to the analytical approach is the time and resources necessary to uncover all the hidden value associated with each potential opportunity. Clearly, a balance must be struck between the costs of estimating and perfecting the financial support for action and the benefits to be derived from such action.

Not all businesses would choose to allocate resources to analyze each and every continuous improvement idea with such rigor. A critical facet of any managers role is determining how and when to transition from analysis to action. Indeed, during this project, pressure was exerted by many key leaders to stop generating analysis and start generating results.

Proposal

Having explored the merits and drawbacks to each method, it seems reasonable to offer a theory on how these two methods can co-exist. In short, the lean philosophy is important in sustaining a responsive and effective culture of continuous improvement and accomplishing more with fewer resources. This is a very efficient process to mobilize a workforce in eliminating obvious and less-complicated sources of waste. The analytical method is necessary to develop well-directed philosophy to attack non-obvious opportunities and for setting priorities to improving profitability. The value of analytics is critical to regain momentum either at the onset of the initiative or after a stall when the initiative is expanded to new departments within the organization. To think that one or the other method is completely correct, will only reduce the total potential that exists in driving operational improvement in the organization.

10 Next Steps

Throughout the project, meetings with the factory management were held to both discuss direction of the work and to convey ideas for improving the business. The following is a summary of the major recommendations to Siemens as they work to continually improve their operations in Frankfurt.

Several projects have been approved by Siemens management and transferred directly to various Siemens personnel in Frankfurt and Erlangen. Following through with these projects will help improve operations and allow for an easier transition of the new product lines designed through Project Portfolio 2008. Successful implementation will require active management support. We also urge that momentum on the three most important projects, which we began, carry forward.

The processes used to develop these ideas are also extremely valuable. Throughout the project, continual transfer of the best ideas and thought processes was accomplished through meetings and data sharing. However, the language barrier proved to limit the value of speech and perhaps directed the project toward a more analytic slant. Though the one-time analysis results were transferred and made a clear point, the usefulness would be short-lived unless Siemens could perform the analysis after the project had ended. Toward this goal, a few master spreadsheets were produced in German (See Appendix) to assist with the calculations that became the focus of our work and project implementations. Material managers and product managers throughout the plant were trained on how to use these calculation tools. It is important that employees continue to objectively evaluate their work as well as the operations around them especially, as we found, at departmental boundaries.

Finally, it is important for Siemens to develop and promulgate well-defined valuations of internal costs and external opportunities for common items such as handling, holding, lead time, setup time etc. Without these, management at all levels cannot be called upon to make objective evaluations of changes and may lack incentive to do so. Frankfurt is a well run plant inside of a well respected international corporation and should be proud of their work. Today's work, however, is the source of future reward and we must look forward to succeed.

11 Summary

As the switchgear industry continues its evolution from air insulated to gas insulated technology, Siemens Frankfurt factory faces the task of introducing a new line of products that not only meet customer needs in terms of function, but is also cheaper and faster to produce than the existing product line. This paper has explored the challenges associated with making the necessary production improvements to support the new product objectives. It is the authors' contention that the Frankfurt factory's existing lean manufacturing initiative is not sufficient to effectively identify all of the potential areas of improvement and implement those that provide the highest value to the factory. Rather, the analytical project framework provided in this paper, in concert with the existing lean efforts, is necessary to adequately steer the Portfolio 2008 effort towards achieving its aggressive cost and lead time goals.

The framework employed over this 9 month internship process involved three primary phases. In Phase I the current processes were researched and mapped using many of the lean value stream mapping techniques. In Phase II, the baseline of process knowledge and performance data was used to identify areas of opportunity and vet them through a rigorous valuation analysis. At the conclusion of Phase II, each area of opportunity has tangible projects identified with detailed cost/benefit analysis all in terms of Euro. Phase III simply identified the 3 most attractive projects in terms of ROI and ease of implementation, carried these projects through implementation, and transferred the remaining project analysis to Siemens project champions.

In reviewing the Phase I process maps, a few general observations were made that helped to characterize the possible improvements to be made:

1. Departments were quite good at optimizing their own process. However, less emphasis was seen on departments working together to reach a global optimum with regards to material and information flow.
2. A high level of re-work was found throughout the process both in the physical production process as well as the order processing and order engineering processes. As these errors occurred later in the process, they were increasingly costly to resolve. By engineering out the errors where they occur, one department may feel an increase

in the total work load, but the overall process will see a reduction in cost and customer lead time.

3. Improving customer lead time can only be achieved by reducing process time along a product's critical path. In the case of the 8DH and 8DJ products, critical paths are quite different. To ensure the most return on lead time reduction project resources, the factory must take the time to understand the current drivers of lead time within the factory.

Once areas of opportunity had been identified, the next step was to provide a rigorous analytical approach to project valuation. To do this, it was important to rethink existing ways of valuing inventory holding costs, material handling costs, and lead time. Lead time reduction, as an example, was primarily thought of as an opportunity to reduce cost of production by lowering parts and work in process inventory levels. But by offering a shorter lead time in this specific product market, Siemens would see an increase in product sales that would also increase total revenue. By considering both cost and revenue impacts, lead time reduction projects become far more favorable to the business. Similarly, valuation of the cost of holding and handling inventory was found to be systematically low. While the total cost of production was accounted for, the detailed costs associated with material handling and costs of scrapping obsolete parts were lost in the factory overhead values. By extracting these values and factoring them into part level inventory optimization models, improvement projects that were considered to be low value were found to yield substantial cost savings.

Additionally, the authors of this paper tried to build on the foundation of literature associated with application of a lean philosophy versus application of rigorous mathematical analysis. The resulting conclusion is that, to be effective, a factory must adopt both a strong continuous improvement culture (such as lean) as well as apply an analytical framework of project for project valuation. Such a framework will not only help align factory leadership when philosophical efforts stall, but also ensure that resources are used most effectively to generate the highest ROI possible.

As the Frankfurt factory moves forward with implementation of the projects identified during this 9 month internship, it is the authors' hope that the analysis framework discussed in this

paper be used on a continuing basis. By establishing a consistent set of standard values for cost of inventory holding, material handling, and lead time, the Frankfurt factory and Portfolio 2008 team can drive ongoing analysis as business conditions change. As well, these methods would be beneficial at a strategic level in understanding the cause and effect relationship between pricing decisions for custom products and the total costs incurred to produce them.

12 Appendices

12.1 Appendix - Screen Shot of Kanban Calculation Tool and Safety Stock Analysis

<u>Nützliche Fakten und Werkzeuge</u> USEFUL DATA & TOOLS			Variation für intern gefertigte Teile	Lieferzeit (Werktage)	Täglicher Unterschied	Koeffizient von Variation	Ausgewählte Prozesse
Overall Data Assumptions (Annahmen)			Variation for Internally Made Parts:	AVG # Work Days	Daily Variance (from Monthly data)	Coeff Var.	Select Processes
Servicegrad	99.9%		Pulvern	0.88	0.07	21%	Paint
Arbeitstage pro Jahr	250		Spruehlackieren	0.76	0.29	51%	Spray Pnt
Lagerkosten (Euro/Auftrag)	11 €		Kunststoff	2.40	3.21	53%	Plastic
Arbeitskosten (Euro pro Stunde)	28 €		Pruefung	0.27	0.01	26%	Test
Koeffizient Abweichung/Lieferzeit	40%		Aluminium	0.96	0.12	26%	Al
Kapitalkosten	10%		Abkanten/Biegen	1.25	0.08	17%	1 Bend
Standardabweichung für selten gebrauchte Teile (Exakte Teile)			Stanzen	1.91	1.30	43%	Stamp
Bestellhäufigkeit (Monate)	6		Schweissen	1.49	0.20	21%	Weld
Order Frequency (months)			Kupfer	2.00	4.90	79%	Copper
jährlicher Bedarf	60		Laserschneiden	1.04	0.12	23%	1 Cut
Annual Demand			Chromatieren	2.68	1.00	21%	Plating
Standardabweichung täglicher Bedarf	2.683		NC-Programmieren	0.87	2.21	122%	1 NC
Standard Deviation of Daily Demand			Durchschnittliche Lieferzeit				Avg. Lead Time
			Durchschnittliche Lieferzeit mit zwei zusätzlichen Transporttagen			5.16	Avg. Lead Time + 2 days transport
			Standardabweichung Lieferzeit			1.55	Standard Deviation of Lead Time

Statistiken	Count	# Removed	Annual Savings	Limits		
	Nummer	# Entfernt	Einsparungen	Grenzen		
Alle Teile	4483		-206,838 €	(' <' oder '>')	All Parts	
Ja		2410	310,349 €		OK	
Zu viele Kanban	888	399	75,085 €	3	Too many Kanbans >=3	
Zu wenige Aufträge	0	0	0 €	0	Too few Orders <=0	
Zu viele Aufträge	144	24	20,950 €	100	Too Many Orders >=100	
Keine Einsparungen	1536	1536	-613,222 €	0	No Savings <=0	
Fehlende Menge	114	(No Box Qty Listed)				

Ask Yourself:
 Can we fit more in a box?
 Should we put fewer in the box?
 Can we fit more in a box? Use larger box?
 How much will this cost?

INPUT DATEN	AUTO-LOOKUP ODER INPUT DATEN			Auto-Schätzung Oder Input Daten		AUTO-LOOKUP ODER INPUT DATEN (Für Kostenkalkulation erforderlich)			METHODE 1: SICHERHEITSBESTANDS KALKULATION		METHODE 2: SICHERHEITSBESTAND HISTORISCH		ENTSCHEIDUNG				EIGENFERTIGUNG KANBAN EINSPARUNGEN					
	(Für Sicherheitsbestand und E-Kanban Kalkulation erforderlich)			Input Daten		erforderlich			Sicherheitsbestand		INPUT: Historisch		Gewählter	Gewählte	Anzahl von Aufträgen		Kommentare	Zusätzliche	LAGER	KAPITALKOSTEN	Gesamte	Alles OK?
	INPUT: Sach-Nummer	Behältnis Kapazität	Lieferzeit (werktagen)	jährlicher Bedarf	Standard abweichung	Standard täglicher Bedarf	Auftragsgröße	Preis (Euro pro Stück)	Rüstzeit pro Aufträge	Sicherheitsbestand (Stück)	Erforderliche E-Kanbans	Höchster Bedarf in Lieferzeit	Erforderliche E-Kanbans	Sicherheitsbestand	E-Kanbans	pro Jahr		Lohnkosten	EINSPARUNGEN	EINSPARUNGEN	Einsparungen	
Suche	84	6.0	1560	2.4	6.24	30	3.14	0.65	66	2.2	75	2.3	71	2	19		-613 €	572 €	-17 €	1,168 €	Ja	
Beispiel	50	4.4	720	1.8	2.9	30	20.00	0.50	25	1.7	26	1.8	25	2	14		-134 €	264 €	-40 €	359 €	Ja	
81896243	30	7.5	160	3.0	1.6	2	22.77	0.69	15	1.6			15	2	5		-1,337 €	823 €	-86 €	2,074 €	Ja	
83252940	42	5.2	300	2.1	1.2	8	9.91	1.06	11	1.4			11	2	7		-978 €	440 €	-47 €	1,371 €	Ja	
81736760	89	6.8	765	2.7	3.1	16	3.64	0.61	36	1.6			36	2	9		-677 €	528 €	-35 €	1,170 €	Ja	
86827180	84	6.0	1560	2.4	6.2	30	3.14	0.65	66	2.2			66	2	19		-613 €	572 €	-17 €	1,168 €	Ja	
81832440	45	3.9	1800	1.6	7.2	225	15.94	0.10	56	2.9			56	3	40		85 €	88 €	397 €	400 €	Zu viele Kanban	
80226690	996	6.0	12800	2.4	51.2	200	1.05	0.36	545	1.9			545	2	13		-512 €	704 €	-103 €	1,113 €	Ja	
80226680	822	6.0	12800	2.4	51.2	200	1.04	0.36	545	2.0			545	2	16		-484 €	704 €	-75 €	1,114 €	Ja	
80220020	18	5.2	4890	2.1	19.6	45	48.60	1.67	186	16.9			186	17	272		7,666 €	1,188 €	-749 €	-7,227 €	Keine Einsparungen	
81736720	112	5.8	600	2.3	2.4	15	6.41	0.69	25	1.3			25	2	5		-673 €	440 €	-87 €	1,026 €	Ja	
80220010	18	5.2	4538	2.1	18.2	45	49.16	1.67	172	15.8			172	16	252		7,123 €	1,100 €	-695 €	-6,718 €	Keine Einsparungen	
80260053	56	7.5	760	3.0	3.0	17	28.22	0.63	38	2.1			38	2	14		-539 €	484 €	-123 €	901 €	Ja	
3555203	30	7.5	328	3.0	1.3	8	35.04	0.69	17	1.9			17	2	11		-559 €	440 €	-92 €	906 €	Ja	
81830950	144	5.8	1840	2.3	7.4	46	1.59	0.63	76	1.8			76	2	13		-483 €	440 €	-19 €	905 €	Ja	
81849550	60	5.2	1522	2.1	6.1	32	4.56	0.57	58	2.5			58	3	25		-362 €	528 €	-36 €	854 €	Zu viele Kanban	
81746980	72	6.0	752	2.4	3.0	19	4.57	0.58	32	1.7			32	2	10		-480 €	440 €	-31 €	890 €	Ja	

12.2 Appendix - Safety Stock & Kanban Calculation Tool Training Document

Safety Stock Analysis

Introduction

Demand and leadtime are inherently variable. We hold safety stock in order to protect from production problems. The cost of holding inventory costs approximately 10% of the inventory value. It is thus important to minimize this inventory, while ensuring with a high level of certainty that we will not have production disruptions. Today, most safety stock choices are made by gut feel and experience of the Disponent. The Sicherheitbestand_und_E_Kanban.xls tool provides an analytical method for calculating proper safety stock levels. The Disponent will use the results of the analysis along with their own knowledge of the material to make a final decision.

Safety Stock Calculation

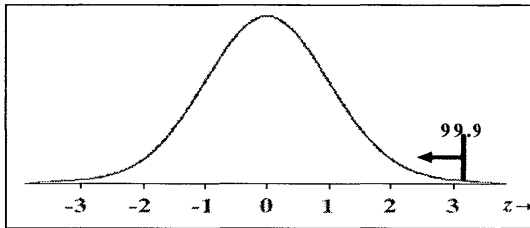
Simple Method:

$$SHB = z * \sigma_{TB} * \sqrt{LZ}$$

Where:

SHB = Sicherheitbestand (Stück)

z = normal distribution factor („standnorminv“ function in excel)



Service Level	z Factor
95%	1.64
99.9%	3.09
99.999%	4.26
99.99999%	5.20

σ_{TB} = Standardabweichung täglicher Bedarf („Stabw“ Funktion in Excel)

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (x_i^2 - N(\bar{x})^2)}{N-1}}$$

LZ = Durchschnittliche Lieferzeit (werktagen)

Complete Method (as used in the Excel tool):

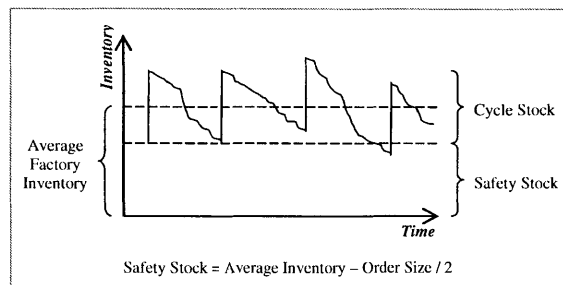
$$SHB = z * \sqrt{\text{MittelwertLZ} * \sigma_{TB}^2 + \text{MittelwertTB}^2 * \sigma_{LZ}^2}$$

Where:

MittelwertLZ = Durchschnittliche Lieferzeit

MittelwertTB = Durchschnittlicher täglicher Bedarf

σ_{LZ} = Standardabweichung Lieferzeit



Spreadsheet explanation

Entering Data:

Columns requiring user input are in green. The row labeled "Lookup" contains formulas that can be pasted into a row for any **material number** to find the appropriate data from the "Alt Daten" tab (containing eigenfertigung part data gathered in August 2006 with demand information pertaining to May, June & July 2006). Alternatively, the data can be determined and entered by the user (the tools on the right side may be helpful). The columns in blue (standard deviation) can either be calculated by the user (alone or with the tools on the right) or estimated using the formula found in the "Lookup" Row. Comments in the title cell (Row 2) explain the estimation method.

Tools on the right side:

The first table contains data assumptions that are used throughout the spreadsheet (default values are 99.9%, 250 workdays per year, 11 Euros per order, 28 Euros per hour, 40% Lieferzeit variation and 10% Holding Cost). The lower left area contains a method to calculate the Standardabweichung täglicher Bedarf für selten gebrauchte Teile (Exakte Teile). Please read the comments for further explanation.

The rightmost tool provides a way to calculate the lieferzeit und Standardabweichung Lieferzeit für eigenfertigung teile if the user knows which preproduction areas are involved in making the part. Enter a "1" in each area that is required.

Calculation:

Method 1 uses the analytical framework presented above. Method 2 uses a worst case analysis, which requires the user to look at SAP data (up to 1 year) to find the highest demand OR to estimate this amount (for most internal parts the average 10 day period (annual demand/25) works well). For internal parts, it is easiest to lookup the highest 5 day period (work week) and use the calculation provided. For external and rarely used parts, it is best to enter the highest demand over a period equal to the lead time directly into the "Sicherheitsbestand (Stück)" column (and delete the data in the "INPUT: Höchste fünf Tage-Periode" column).

Finally the Disponent (or other user) will use their knowledge of the material along with the calculation to make a final decision on the proper level of safety stock. Comments can be entered to document your reasoning.

Eigenfertigung Kanban Analysis

Introduction

An important improvement philosophy at the Frankfurt plant is to implement Eigenfertigung Kanban (E-Kanban). Major savings can be achieved by eliminating the extra movement of materials through the warehouse, but related costs must also be understood. Increased setup times can result from decreased batch sizes and space on the production line is limited. The Sicherheitbestand_und_E_Kanban.xls tool provides an analytical method for calculating the savings, number of kanbans required and evaluating the decision for E-Kanban conversion.

Spreadsheet Explanation

Using the input data (explained above), the spreadsheet also uses 2 different methods to calculate the kanban size. Method 1 uses the idea that while one box is being filled, the remaining boxes must hold the safety stock and the lead time demand. Per the philosophy at the Frankfurt plant, it is always assumed that the size of a kanban will be equal to the box capacity. Method 2 uses the idea that while one box is being filled, the remaining boxes must hold the highest possible demand during the lead time.

The Eigenfertigung columns calculate annual cost changes for each part converted to E-Kanban. "Zusätzliche Lohnkosten" is the cost of setup time. „LAGER EINSparungen“ comes from eliminating the handling of orders at the warehouse. KAPITALKOSTEN EINSparungen" comes from the change in the average inventory level.

The column labeled "Alles OK?" explores several areas of potential conflict that might prevent the part from being converted to E-Kanban. These potential conflicts are listed in the Statistiken box. Here, the limits can be modified (example: Zu wenige Aufträge is the minimum number of annual orders needed. If the number of orders is less than this amount, the "Alles OK?" column will note a conflict). If there are multiple conflicts, only one is listed. The Statistiken box provides further information about the savings that could be achieved and the number of parts in each category.

12.3 Appendix - Inventory Optimization Methodology & Batch Size Derivation

Inventory Optimization Methodology

- a. Costs Considered
 - i. Setup Labor Cost (28 Euro/hr, Setup times from Arb.plan)
 - ii. Holding Cost (7% cost of capital + 3% for obsolescence)
 1. Cycle Stock (reduced by smaller batches)
 2. Safety Stock (reduced by lower lead time)
 - iii. Warehousing & Handling Cost (11 to 12 Euro per incoming order)

- b. Optimization
 - i. Calculate Optimize Batch Size (B^*) – see derivation below
 - ii. Bypass Warehouse and solve for TC_2
 1. Check validity per constraints
 - a. Number of kanbans (space on line)
 - b. Number of orders per year (turnover)
 2. Revisit invalid TC_2 solutions & evaluate modifications
 - a. Can more/less be placed in a box?
 - b. Would a different box type be more appropriate?
 - iii. Minimum of TC_1 and valid TC_2 is Optimal Solution; TC_3
- c. Prioritize evaluated part list by Total Savings (TC_3 – original cost)

Derivation of Optimal Batch Size

Abbreviations:

TC = Total Cost

SL = Setup Labor Cost

CSH = Cycle Stock Holding Cost

SSH = Safety Stock Holding Cost

WH = Warehouse Storage and Handling Cost (recoverable portion only)

B = Batch Size

B* = Optimal Batch Size

Total Cost Formulation:

$$TC = SL + CSH + SSH + WH$$

$$SL = \text{hours/order} * \text{cost/hour} * \text{orders/year} \quad \& \text{ orders/year} = (\text{qty/year})/\text{Batch Size}$$
$$SL = C_1/B$$

$$CSH = \text{Average Inventory} * \% \text{ holding cost} = B/2 * \text{price} * \% \text{ holding cost}$$
$$CSH = C_2 * B$$

$$SSH = \text{safety stock level} * \% \text{ holding cost}$$
$$SSH = C_3$$

$$WH = \text{recoverable cost/order} * \text{orders/year} \quad \& \text{ orders/year} = (\text{qty/year})/\text{Batch Size}$$
$$WH = C_4/B$$

$$TC = C_1/B + C_2 * B + C_3 + C_4/B$$

Optimal Batch Size Determination:

*Set Derivative of Total Cost equal to zero to determine Optimal Batch Size

$$TC' = \frac{\partial TC}{\partial B} = \frac{-C_1}{B^2} + C_2 + \frac{-C_4}{B^2} = 0$$

$$B^* = \sqrt{\frac{C_1 + C_4}{C_2}}$$

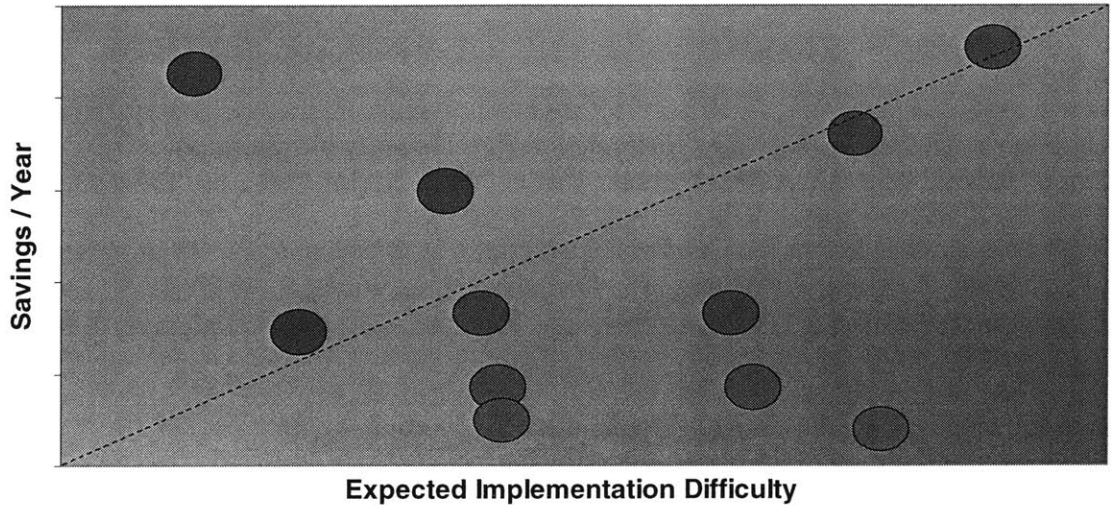
*Note that safety stock holding cost does not affect the optimal batch size

12.4 Appendix - Future Vision for Factory Operations

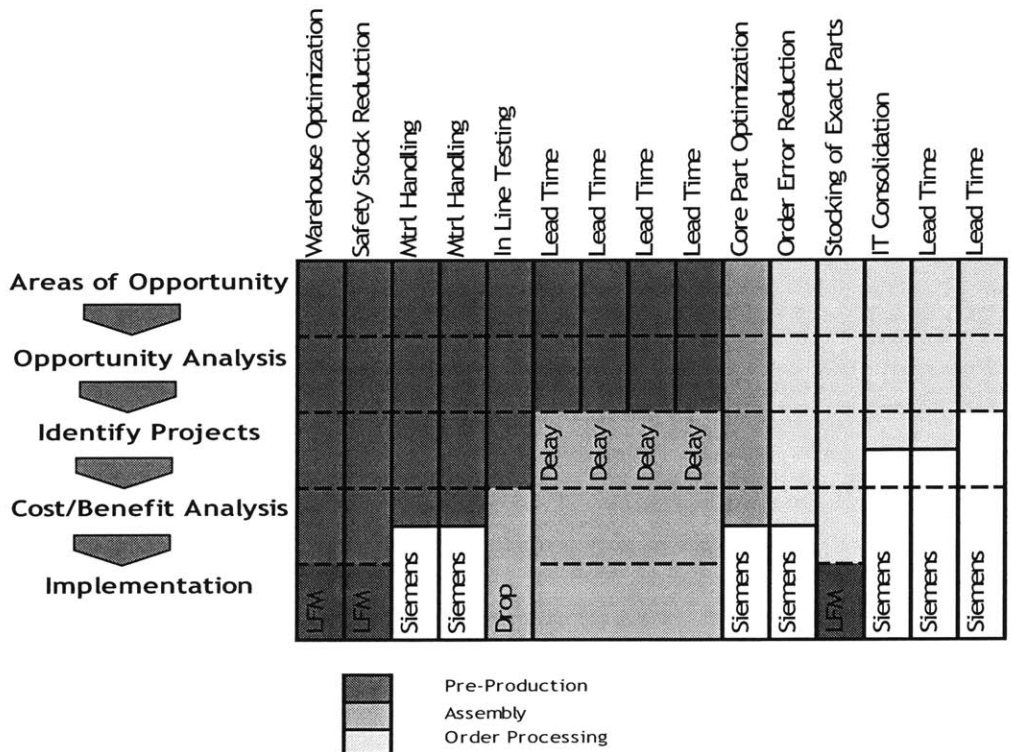
CURRENT WORK FLOW			5 Days	POSSIBLE WORK FLOW			<1 Day
Value Added (Hours)	8DH	Non-Value Added (Hours)		Value Added (Hours)	8DH	Non-Value Added (Hours)	
0.5	SAP Order Queue	12.0		0.5	SAP Order Queue	0.5	
	Laser Weld				Laser Weld		
0.5	LWelded Queue	2.0		0.5	LWelded Queue	0.5	
	Hand Weld				Hand Weld		
1.5	Welded Queue	24.0		0.5	Welded Queue	0.5	
	Core Assembly				Core Assembly		
0.5	Core Queue	1.0		1.5	Core Queue	0.0	
	Back/Fill/Weld				Core Queue		
0.5	Finished Core Queue	0.5		0.5	Back/Fill/Weld	0.0	
	Core Part Test				Finished Core Queue		
0.5	Tested Core Queue	8.0		0.5	Core Part Test	0.0	
	Final Assembly 1				Tested Core Queue		
2.0	In-Line Buffer	3.5		2.0	Final Assembly 1	1.0	
	Join				In-Line Buffer		
0.3	In-Line Buffer	1.0		0.3	Join	0.5	
	Final Assembly 2				In-Line Buffer		
6.3	Final Assembly NVA	3.5		6.3	In-Line Buffer	0.0	
	Test	48.0			Final Assembly 2		
	Final Assembly NVA				Final Assembly NVA	0	
	Test				Test	2.5	
12.2	ALL	104		12.2	ALL	5.5	
11%	116	89%		69%	18	31%	
8.7	Final Assembly	56		8.7	Final Assembly	3.0	
13%	65	87%		74%	12	26%	

This graphic was intended as a representative example of the Frankfurt assembly process. It highlights the 8DH assembly process from the time the customer order is released to the core part manufacturing department until final testing. The current flow was taken from the phase I process mapping exercise. The possible work flow represents a cumulative view if all of the identified areas of opportunity valued in phase II were successfully implemented.

12.5 Appendix - Project Selection Graphs



● LFM Implementation ● Siemens Implementation



13 Bibliography

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ⁱⁱ www.siemens.com

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