THE VALUE OF A COMMON APPROACH TO LEAN

by

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Abstract:

ABB is a world leader in power and automation technologies working to enable utility and industry customers to improve operations. Competition in these markets is increasing and in order to retain their competitive position, ABB must strive to improve their operations by reducing costs and delivery times. Most ABB factories still operate on push principles with long throughput time, high inventories, and high overhead In order to remain competitive these factories have decided to transform their businesses reduce costs and increase speed. The strategy to achieve this in the power technologies distribution transformer (PTDT) factories is to develop a standard approach to lean manufacturing for implementation in factories around the world.

The thesis will describe standard approaches to lean proposed by academics and used by other leading companies; analyzing at the frameworks used including implementation practices, tools, and results. With an understanding of how other companies implement lean manufacturing techniques, this thesis will then describe the creation of a standard approach to lean for ABB PTDT factories, examining the methodology of the approach including the implementation process, common production practices, tools used, and evaluation techniques.. Two case studies will be used to describe the implementation of these lean manufacturing techniques at the Monselice, Italy and Zaragoza, Spain factories.

Using the Monselice and Zaragoza case studies, along with results seen by other companies, this thesis will analyze the benefits of a standard approach to lean as it relates to the creation of a corporate culture, improvements in implementation results, and increasing ease of implementation.

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Chapter 1. Introduction and Thesis Overview

1.1 Project Motivation

"We have it in our own hands to increase productivity, do more for our biggest customers, leverage our size and scope and explore key market niches. I know that we are asking a lot of our leaders at all levels, and all of you, but we have no choice. So let's keep our focus on the business, while we streamline ABB and lay the groundwork for a better future."[1] Quote from Jürgen Dormann, Chairman and CEO of ABB

ABB's history of growth through acquisition of smaller companies has created a company with diverse organizational and operational practices. Generally, companies acquired by ABB, have had a profitable history in local markets, so few changes had been required. Even though profitable, many ABB factories still operate on push principles, with long lead times, quality problems, excessive inventory and overhead. In order to remain competitive in today's market these factories must be transformed to reduce costs and time to market.

1.2 Company History

ABB was created in 1988 when the Swedish company Asea and the Swiss company BBC Brown Boveri joined. The corporate vision was to create a global company that could take advantage of economies of scale, while maintaining a local presence to acquire contracts with local governments within local markets. The result was a matrix organization with very decentralized management.

ABB is a supplier of power and automation technologies to both utilities and industry customers. The company has approximately 140,000 employees, more than 300 factories and operates in more than 100 countries around the world.[2] ABB's products and

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[1] Homepage <http://inside.abb.com>
[2] ABB Group Annual Report 2002 (ABB Limited of Switzerland).

services are separated into two core divisions ABB Power Technologies and ABB Automation Technologies.[3]

ABB Power Technologies serves utilities, industrial and commercial customers with products for power transmission, distribution and power plant automation. Products produced include transformers, apparatus, cables, switchboards, circuit breakers, and other products for high and medium voltage applications.[4] ABB Automation Technologies serves utilities and process industries with products that provide control, motion, protection and plant integration. Products produced by the Automation Technologies division include instrumentation, robotics, drives, motors, and various low voltage products.[5]

ABB's history of matrix organization and growth through acquisition has resulted in a collection of individual plants, each with their own culture, goals and metrics. Each plant is regarded as profit center, increasing the competition between individual plants. The traditional view on optimization of the enterprise as a whole has been to address optimization at each plant individually. This resulted in poor economies of scale and did not allow the enterprise to leverage all plants to improve the company as a whole.

In 2002 ABB experienced significant financial troubles due to record losses, plummeting stock price, utility deregulation, controversy over pension payments, asbestos troubles, and underperforming operations; As a result, ABB is now facing pressures to drastically improve their businesses. The previous matrix organizational structure has given way to a divisional organizational structure, where each division has common shared services such as information systems and human resources. ABB is also creating policies for using common suppliers and is working toward increasing cooperation and knowledge sharing between plants. Using this approach, ABB will be better positioned to leverage the experiences and product knowledge of its various facilities in ways, which were challenging under the previous matrix structure.

[3] ABB Group Annual Report 2002 (ABB Limited of Switzerland).
[4] Ibid.
[5] Ibid.

1.3 Project Setting and Goals

The project was completed with ABB's Power Technologies Distribution Transformer (PTDT) Business Area. The PTDT division is comprised of 34 factories around the world, producing liquid filled, dry, and cast distribution transformers. Each factory has different manufacturing processes, historical background and plant culture, but all are being pressured to improve their operating processes.

The project is being undertaken in partnership with ABB's Corporate Research Center (CRC) in Vasa, Finland. ABB has eight corporate research centers around the world. The research centers focus on developing technologies and improving processes in factories and each of the eight centers has a different area of expertise. The ABB Corporate Research Center in Finland specializes in manufacturing improvements such as lean manufacturing, production scheduling, supply chain management and supporting IT systems.

In order to accomplish the corporate goal of reducing costs and time to market, the PTDT Business Area has collaborated with the CRC to create a common lean manufacturing approach to be implemented in factories around the world. The premise is that having a common approach to implementing manufacturing improvements will simplify the implementation and improve the speed at which this can be achieved; i.e., each plant becomes a pilot for the next and establishes a record of success for future implementations.

The project has three main goals:

1. Work with both the PTDT division and CRC project managers to formalize the common approach to lean and create a "transferable" product describing the tools and processes.

2. Implement all aspects of the ABB lean manufacturing practices at the pilot site in Monselice, Italy.

3. Implement lean manufacturing practices at the project rollout factory in Zaragoza, Spain, focusing on coordinating supply chain improvements.

1.4 Thesis Overview

This thesis will explore the subject of the value of a common approach to lean. Chapter 2 will provide a description of how other companies and academia suggest approaching lean implementations including a literature review on the framework, tools and processes used. Chapter 3 will describe the formalized approach for implementing lean manufacturing at ABB PTDT factories created during this project. Chapters 4 and 5 will discuss the implementations at both the pilot (Monselice, Italy) and rollout (Zaragoza, Spain) sites. Chapter 6 will examine the value of a common approach to lean based on the experiences acquired during the implementations in Monselice and Zaragoza.

Chapter 2. Lean Operating Systems at Leading Companies

This chapter provides an overview of lean operating systems and presents examples of academia and industry frameworks used for implementing these systems. The chapter begins by defining what an operating system is and what should be included. With this as a foundation, the chapter highlights how academic thinkers, such as Womack and Jones[6] and the Lean Aerospace Initiative, at the Massachusetts Institute of Technology, recommend implementation be conducted. Lean implementations at Toyota and other top manufacturing companies such as Boeing, Hamilton Sundstrand, Ford, and Kodak are also described.

2.1 Operating System Defintion

An Operating System describes, simply, how a company operates, providing structure for implementing change on a continuous basis. It is a framework that describes the "ingrained" way of doing things at the company. In his paper, Transforming How We Work[7], Jamie Flinchbaugh describes the required elements of an Operating System. According to Flinchbaugh an operating system integrates:

- Thinking (alignment in thinking to build culture)
- Systems (vital work processes, the way work gets done)
- Tools (generate new approaches)
- Evaluation (understand where you are and where you are going)

Flinchbaugh notes that an operating system is a way of getting agreement on what needs to be done and how it should be done. He proposes a four-part framework to analyze operating systems. The four domains of the framework include; thinking, systems, tools, and evaluation.

[6] Daniel T. Jones, and James Womack founded the Lean Institute and have written many authoritative books on the subject.
[7] Jamie Flinchbaugh, "Transforming How We Work"

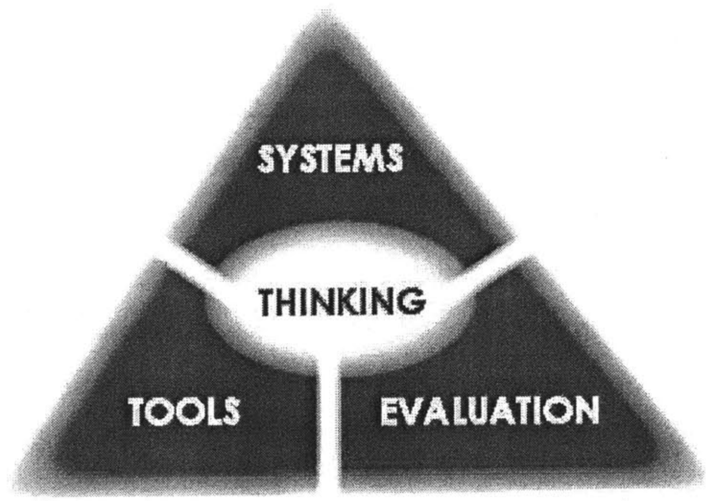

Figure 1: Operating System Framework.[8]

Thinking is defined as the axiomatic beliefs that employees should hold when solving problems and making decisions. It is placed in the center of the diagram due to its centrality in any successful operating system. The thinking piece of an operating system defines how employees perceive and interpret their world. It forms "a lens or filter through which we observe everyday work to see gaps between the current state and ideal state."[9]

Systems describe how the business is run with respect to process execution and management. It includes aspects such as work management processes and decision-making.

Tools define how a company operates on a day-to-day basis. Companies have many choices when selecting tools to define their lean operating system. One common mistake many companies make is selecting too many tools. Tools should be selected that best match the characteristics of the organization and included in existing operating systems.

[8] Jamie Flinchbaugh, "Transforming How We Work"
[9] Ibid.

Evaluation allows a company to quantify their lean transformation and help direct the "next steps". Common evaluation methods used are key performance indicators, employee surveys, and lean assessments.

These four operating systems aspects will be used to examine each of the following lean implementation examples.

2.2 Lean Thinking

In their book, *Lean Thinking*, Womack and Jones define the key principles of lean manufacturing.[10] *Lean Thinking* examines each of these principles in detail and provides examples of how they were used in lean implementations at multiple firms from a wide range of industries around the world. Using the research done on these firms, the authors summarize their lessons learned by providing a specific sequence of steps to obtain the best lean implementation results.

2.2.1 Thinking Domain: Five Principles

Lean Thinking summarizes lean with five key principles. These principles provide a high-level framework that allows people to understand the whole lean system.

- Identify Value
- Map the Value Stream
- Flow
- Pull
- Perfection

2.2.2 Systems Domain: Implementation Process

Based on the lessons learned from researching multiple lean transitions, *Lean Thinking* describes an implementation process to use when implementing lean. The process described is divided into four phases:

[10] Dan Jones, and Jim Womack, Lean Thinking, (Simon & Schuster, 1996).

Getting Started:

- Find a change agent
- Get the knowledge
- Find a lever by seizing the crisis, or by creating one
- Forget grand strategy for the moment
- Map your value streams
- Begin as soon as possible with an important visible activity
- Demand immediate results
- As soon as you've got momentum, expand your scope

Creating an Organization to Channel Your Streams:

- Reorganize your Firm by Product Family and Value Stream
- Create a Lean Promotion Function
- Deal with Excess People at the Outset
- Devise a Growth Strategy
- Remove the Anchor Draggers
- Once you have fixed something, fix it again.
- Two steps forward and one step backward is OK; no steps forward is not OK

Install Business Systems to Encourage Lean Thinking:

- Utilize policy deployment. Create a lean accounting system.
- Pay your people in relation to the performance of your firm.
- Make everything transparent.
- Teach lean thinking and skills to everyone.
- Right size your tools.

Completing the Transformation:

- Convince your suppliers and customers to take the steps just described.
- Develop a lean global strategy.
- Convert from top-down leadership to bottom-up initiatives.

2.3 Lean Aerospace Initiative

In 1993, the US Air Force questioned if the principles of lean manufacturing could be applied to the manufacturing of military aircraft. MIT formed a consortium called the Lean Aerospace Initiative with government agencies such as NASA, the U.S. Air Force, U.S. Army and U.S. Navy and industry partners in the airframe, engine, avionics and space industries. The book *Lean Enterprise Value*[11], provides a description of how organizations can apply "lean thinking" to create enterprise wide transformations based on research performed by the Lean Aerospace Initiative. Although the book focuses mostly on aerospace companies, the general ideas are applicable to all industries.

2.3.1 Thinking Domain: Lean Enterprise Principles

Based on the research done by the Lean Aerospace Initiative, *Lean Enterprise Value* proposes six key principles that characterize a lean enterprise, noted as the core principles of a lean enterprise.

- Waste minimization
- Responsiveness to change
- Right thing at right place, at right time, and in right quantity
- Effective relationships within the value stream
- Continuous improvement
- Quality from the beginning

2.3.2 Systems Domain: Transition to Lean Roadmap

The issue of how to transform an enterprise is also described in the book. A roadmap framework is used to define the overall sequences of actions that need to be taken to initiate, sustain, and refine a lean transformation. The roadmap addresses what the key success factors are and creates three interdependent cycles that help companies identify progress in lean transformation and where to go next.

[11] Thomas Allen, et al. Lean Enterprise Value (New York: Palgrave, 2002).

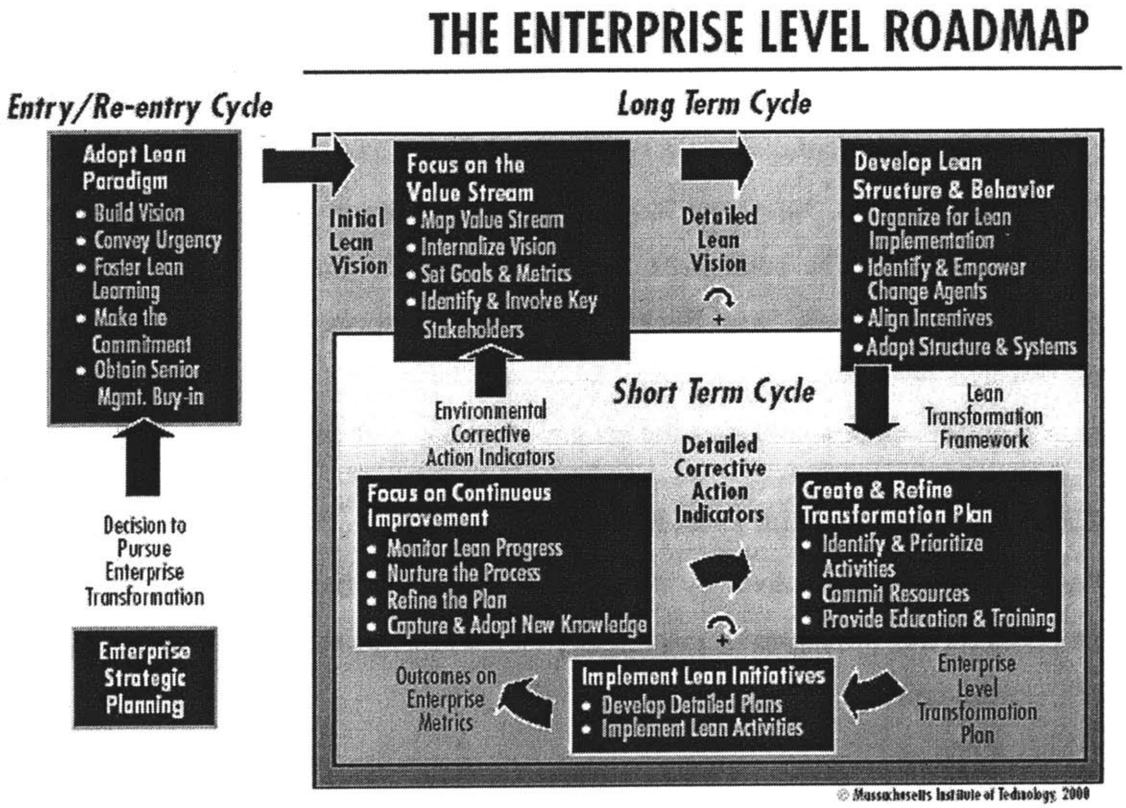

Figure 2: Enterprise Level Transition To Lean Roadmap Structure

2.3.3 Evaluation: Lean Enterprise Self Assessment Tool

In order to provide a tool for understanding where companies are in their enterprise transformation, the Lean Aerospace Initiative has created a Lean Assessment tool. The idea of the tool is to measure the 'lean-ness' of a company and identify the companies desired future state.

2.4 Toyota Production System

After World War II the Toyota Motor Company pioneered the Toyota Production System. Since then their approach has been used as the foundation to define production systems at companies around the world. The approach is documented in numerous publications including Taiichi Ohno's book *Toyota Production System*[12].

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[12] Taiichi Ohno. Toyota Production System (Portland: Productivity Press, 1988).

2.4.1 Thinking Domain: Guiding Concepts

The Toyota Production System is defined by two guiding concepts. These are the two core concepts that Toyota hopes employees will use when solving problems and making decisions.

1. Just-In-Time is the production of ordered units at the right time.
2. Autonamation, or jidoka, is a tenet of quality control that says products should not flow downstream if they are defective.

2.4.2 Systems Domain: Main Elements

The implementation of the Toyota Production System is described by the four main elements.

1. Eliminate Waste from the system
2. Reduce Setup Time
3. Balance and level production
4. Establish Kanban and Just-in-Time systems

2.4.3 Tools Domain: Toyota Production System Tools

Because the Toyota Production System is the foundation of what lean is today, the tools of the Toyota Production System are similar to the tools used in most lean manufacturing implementations.

Kanban System, Production Smoothing, Set-Up Time Reduction, Standardization of Operations, Manufacturing Cells, Worker Involvement, Trained Workforce , Visual Control System , Continuous Improvement , "Five Whys" Analysis

2.5 Ford Production System

The Ford Production System is a framework of principles and processes that were created with the goal of improving manufacturing capabilities while capturing the heritage of Henry Ford's original production system. The ultimate objective of the Ford Production System is to improve Ford's strategic business objectives: safety, quality, delivery, cost, morale, and environment.

2.5.1 Thinking Domain: Main Elements

Dwight Johnson describes the Ford Production System main elements in his thesis, *Design of a Systems Based Plant Assessment Process.*[13]

Ford Total Productive Maintenance (FTPM):
Manufacturing Engineering
In-Station Process Control
Managing
Training
Workgroups
Synchronous Material Flow
Industrial Material Flow
Safety
Environmental
Quality

2.5.2 Systems Domain: Implementation Process

According to Dwight Johnson, lean implementations at Ford are phased through a five part process:

1. Stability
2. Continuous flow
3. Synchronous Production
4. Pull System
5. Level Production

2.5.3 Tools Domain: Ford Operating System Tools

Johnson describes the tools Ford uses as part of the Ford Operating System at a higher more abstract level and divides them into three major areas:

- Flexible, Capable, Highly Motivated and Empowered People
- Continuously Flowing Material and Products

[13] Dwight David Johnson, "Design of a Systems Based Plant Assessment Process", (Masters Thesis, Massachusetts Institute of Technology, 2002).

- World Class Reliability and Maintainability

2.5.4 Evaluation Domain: Ford Production System Measurables

Rich Welnick describes the Ford Production System Measurables in his thesis *Applying Lean Manufacturing Principles in an Automotive Stamping Plant.* According to Welnick, Ford uses metrics called "FPS Measurables" to track performance. These are intended to measure performance of plants and help identify where operations need to be improved. The seven FPS measurables include:[14]

1. Overall Equipment Effectiveness (OEE)
2. First-Time-Through
3. Build to Schedule
4. Dock-to-Dock
5. Total Cost
6. Safety and Health Assessment Review Process (SHARP)
7. Attitude Surveys

In addition to the Measurables, Ford also conducts Integrated System Reviews (ISR). The ISR is performed by assessors and coaches from corporate offices. They review each plant annually to determine a score and level for ach FPS element. These scores are then compiled to determine an overall score for the plant.

2.6 Boeing Lean Enterprise

The Boeing Company, Commercial Airplanes Group, began implementing lean techniques such as Just-in-Time and Total Quality Management in the late 1980s. In 1993 the company began to focus its operations in overall lean practices and created a system called Lean Enterprise to implement lean into their production process. It is described using a three-part framework including the main elements, nine tactics, and implementation tools.

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[14] Richard J. Welnick, "Applying Lean Manufacturing in an Automotive Stamping Plant", (Masters Thesis, Massachusetts Institute of Technology, 2001), 18-19.

2.6.1 Thinking Domain: Three Key Principles

The implementation of lean at Boeing is focused around three key principles.[15] Each of the following elements are important areas of focus for manufacturing operations. The three principles are:

1. Takt Paced Production: Using the customer rate of demand to determine the rate of assembly in a factory. Takt based production ensures that production occurs at the right pace to meet customer needs on time.

2. Pull Production: Products are made only when the customer requests them, ensuring that products are only built when needed.

3. One-Piece Flow: Products are made one at a time instead of in batches. Producing products in such a manner improves quality and lowers costs.

2.6.2 Systems Domain: Nine Tactics

Victoria Gastelum describes the nine tactics Boeing uses to sequence lean transformations in her thesis *Application of Lean Manufacturing Techniques for the Design of the Aircraft Assembly Line*[16]

1. Understand how value flows: Defining major processes and sequences of the process required to build products.

2. Balance the line: Work to evenly distribute work across different process areas in order to optimize flow time.

3. Standardize work procedures: Create standard work procedures to ensure high quality output and determine process abnormalities.

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[15] Home Page <http://www.boeing.com/commercial/initiatives/lean/lean_summary.html#>.
[16] Victoria Gastelum, "Application of Lean Manufacturing Techniques for the Design of the Aircraft Assembly Line", (Masters Thesis, Massachusetts Institute of Technology, 2002).

4. Put visual controls in place: Place visual systems in the factory to help employees instantly understand factory performance and determine areas where problems exist.

5. Put everything at point of use: Place parts, tools, information and equipment where people need it to perform their jobs.

6. Establish feeder lines: Take pre-assembly tasks and perform them off the main production line to reduce parts and improve focus in the assembly area.

7. Radically redesign products and business processes: Brainstorm with employees to find breakthrough process redesigns to improve factory processes.

8. Convert to a pulse line: Position products in a straight-line configuration. The production line is moved forward once all work is complete.

9. Convert to a moving line: Products are continuously moved along a production line at the rate of customer demand. The line is only stopped when problems are detected.

2.6.3 Tools Domain: Boeing Tools

Implementation is centered on two main tools; employee empowerment and value stream mapping[17]

Employee empowerment and involvement

AIW's - Accelerated Improvement Workshops: AIW's are similar to Kaizen events and are a combination of training, planning, and implementation to make rapid improvements on the factory floor.

[17] Home Page <http://www.boeing.com/commercial/initiatives/lean/lean_summary.html#>.

AMW – Accelerated Maintenance Workshops: operators and maintenance employees use these workshops to define responsibility for the daily care of critical component checks.

LMA – Lean Manufacturing Assessments: Representatives from every function perform assessments by documenting the existing process, identifying improved methods to do the same work and developing an implementation plan to move from the current methods to the newer improved process

Production Preparation Process (3P) Workshops: The focus of these workshops is on (re)designing waste out of parts, equipment, and processes.

Value Stream Map

Value stream mapping is used to visualize the total product flow describing the process used to bring a product from raw material to the hands of the airline customer.

2.7 Hamilton Sunstrand Operating System

Jonathan Rheaume describes the Hamilton Sunstrand lean improvement operating system, Market Rate Demand (MRD), in his thesis *High Mix, Low Volume Lean Manufacturing Implementation and Lot Size Optimization at an Aerospace OEM*[18]

2.7.1 Thinking: Standard Principles

According to Rheaume, MRD advocates the following standard principles:

- Respect for people
- Teamwork
- Elimination of waste
- Simplification of product flow
- Standardization of product flow
- Management of the process, not the product to attain quality
- Produce to demand
- Single piece flow

[18] Jonathan M. Rheaume, "High Mix, Low Volume Lean Manufacturing Implementation and Lot Size Optimization at an Aerospace OEM", (Masters Thesis, Massachusetts Institute of Technology, 2003).

2.7.2 Systems Domain: Implementation Process

Rheaume describes how MRD Implementations are phased through a 10 step process:

1. Kick-off of cross-functional team and perform overview training
2. Initial Data Collection
3. Process Analysis
4. To-Be Process Definition
5. Resource Requirement Calculations
6. Kanban Design Analysis
7. Define Cell Layout / Simulation
8. Final Presentation
9. Equipment Procurement / Transition Plan
10. Implementation

2.7.3 Tools Domain: MRD Tools

According to Rheaume, Hamilton Sunstrand uses a variety of familiar lean tools to implement their MRD improvement projects. Some of these tools include:

> Process Flow Maps, Routing By Walk Around, Part/Process matrix, Identification of Design, Quality, Supplier, Material issues, Overall Equipment Effectiveness, Analyzing Demand Pattern, Creation of Part Families, Development of Standard Processes, and creation of work cells.

2.8 Kodak Operating System

In the article *How Kodak Developed Its Own Brand of Lean*[19] author Duff McCutheon describes the history of the Kodak Operating System. Five years ago Eastman Kodak decided that the future of their company depended on implementing lean manufacturing. In 1998, they created their own approach to implementing lean and called it the Kodak Operating System. McCutheon explains that at the time, other manufactures questioned "how could a continuous process operation like Kodak – which produces photographic film, papers and chemicals, motion picture films, diagnostic imaging film and equipment

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[19] "How Kodak developed its own brand of lean," Advanced Manufacturing (2003) <http://www.advancedmanufacturing.com/October03/coverstory.htm>.

– apply the lean concepts that worked for assembly operations?" With the creation of a system known as the Kodak Operating System Kodak has proven that lean can be applied outside of assembly areas, including process oriented companies.

2.8.1 Systems Domain: Three Main Principles

The article describes the Kodak Operating System as centered around three main principles; Just-In-Time (JIT), Jidoka, and Heijunka.

- Just-in-time means delivering to the customer exactly what they need, when they need it and in the amounts needed accomplished with the minimum amount of resources.

- Jidoka is immediately responding to problems with the process and finding their root cause to prevent the problem from happening again

- Heijunka is defined as production leveling. This means focusing on the rate at which customers are demanding products and leveling production to match the demand.

2.8.2 Thinking Domain: Implementation Process

In her thesis *Development of a Methodology for the Rapid Implementation of a Sustainable Lean Manufacturing System* Olapeju Popoola describes the five-phase implementation process created by Kodak.[20] It is composed of five lean elements; stability, continuous flow, synchronous flow, pull system, and leveled production.

1. Stability: The first phase is focused on creating consistent and capable production where operational performance targets are well defined and can be obtained in a predictable and repeatable manner
2. Continuous Flow: The second phase works on improving the flow between successive processes by reducing buffers such as safety stock.

[20] Olapeju A. Popoola, "Development of a Methodology for the Rapid Implementation of a Sustainable Lean Manufacturing System", (Masters Thesis, Massachusetts Institute of Technology, 2000).

3. Synchronous Flow: The third phase attempts to ensure that manufacturing is paced to external customer demand. This is a difficult goal at Kodak due to the significant batch processing performed.
4. Pull System: The fourth phase, pull system, is used to control production based on customer demand. Production is performed at upstream processes based on downstream requirements.
5. Production Leveling: The final phase involves leveling production over a defined period of time using tools such as takt time and heijunka boxes.

2.8.3 Tools Domain: Kodak Operating System Tools

The tools selected by Kodak are common lean tools used across industries. According to Popoola, the main tools of the Kodak Operating System include:

> 5S, Visual Management, Single Minute Exchange of Dies, Total Productive Maintenance, "Mistake Proofing", Standardized Work, Kaizen, Focus on WIP Reduction, Reduce Batch Sizes, Station to Station Flow, Cross Training, Takt Time, Heijunka Box, Pull systems, Kanbans, Inventory Buffers, Implement Reorder Points, Supermarkets, and Pitch – Time Leveling

2.9 Summary

As shown in the section above, there are multiple ways to approach creating a Lean Operating System. Comparison of academics who recommend frameworks and companies that have successfully created their own shows both similarities and differences. Each of the descriptions above illustrates similarities to the Toyota Production System including related language and tools. Another common theme is the idea of using a phased implementation focusing first on figuring out how your company provides value, then fixing the current processes in place by improving factory flow, next moving on to creating pull production, and then concluding by continuing to perfect the process.

Although there are many similarities, it is evident that each of these companies has crafted a specific approach that works best with their production environment and culture. As part of this project, a specific approach to lean was created for ABB. The benchmarking described in this chapter was used to compare how other companies approach lean and create a framework for ABB. This operating system and the framework used to describe it is described in detail in Chapter 3.

Chapter 3. Common Approach to Lean for ABB - PTDT

3.1 Historical ABB Lean Approach

Historically, ABB has had no centrally defined vision for lean manufacturing. Factories have individually implemented "pieces" of lean either through their own initiatives or with assistance from the CRC. This approach has allowed areas to customize lean manufacturing techniques, crafting the implementation to fit their own local needs. While allowing for customized solutions, this approach has not taken full advantage of the ABB matrix structure or provided an infrastructure for shared learning across factories.

3.2 ABB Common Pull Production Practices

In 2002, it was decided that a structured approach should be created for lean implementation in ABB's PTDT factories. The approach, Common Pull Production Practices (CP3), was created based on the internal knowledge of Corporate Research Center consultants and external benchmarking of other companies standard approaches to lean.

During this project, the CP3 approach was formalized into a concept that could be transferred to many sites. Using both the benchmarking from external companies described in Chapter 2 and internal knowledge of ABB process ABB's CP3 approach was created. CP3 was designed such that it would be "generic" enough to allow individual factories to tailor certain aspects of the approach to fit their individual needs, yet specific enough to provide common tools required to accomplish the implementation. The CP3 framework is divided into three primary areas, implementation process, common practices, and implementation tools. Each area is described in more detail in the following sections.

3.3 Principles: Practices Used in CP3

The main areas of focus for CP3 are Continuous Flow, Pull Production Control, and Synchronizing the Value Chain. These practices are chosen, because they directly impact throughput and minimize work-in–process (WIP), and thereby minimize the cycle times.

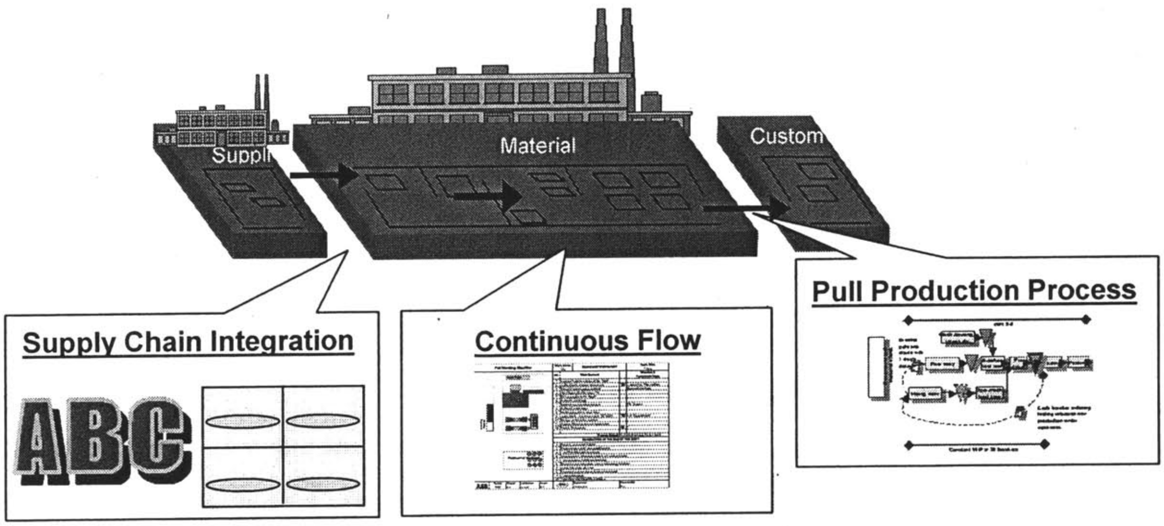

Figure 3: Principles of CP3 Overview

3.3.1 Continuous Flow

Continuous flow can be summarized as make only what is needed, when it is needed, and in the amount needed. Products that flow through the factory and have to sit and wait in different areas have throughput times, which are much longer than required. An organization with perfect flow would have no waste, no inventories, no storage space, no transportation, and no queues. Continuous flow focuses on linking sequential operations with each other in order to align the steps needed to get the job done in a continuous manner. This requires focusing on the total processes instead of optimization of individual resources.

Each of the seven types of waste described in lean manufacturing is an evidence of non-continuous flow. The 7 wastes in lean manufacturing are: Over-production, Waiting, Transportation, Excess processing, Excess inventory, Excess motion, and Quality Defects. With reductions in these wastes, it is possible to increase the speed with which a product flows through the plant while decreasing costs.

Implementing *flow* has a major impact on the factory bottom line. Cash flows will be increased because products will get to the customer faster allowing payment to be collected sooner and money to be invested earlier. As inventory sizes are cut, fewer parts will be lost, damaged, or become obsolete due to engineering changes. Work in process will be reduced allowing better control of problems since quality issues will no longer be hidden in inventory. Less floor space will be required because WIP, inventory and non-value added movements have been reduced.

3.3.2 Pull Production Control

Pull Production is a method of ensuring that products are not made until the customer, or next process step, requires them. In a successful production control implementation the start of one job is triggered by the completion of a prerequisite one. Production control systems such as Kanban, ConWIP and Drum/Buffer/Rope each provide different benefits to different working environments.

To implement a pull production system successfully it is important to understand the resources of the factory and their capacity to perform work. Each factory process has a finite capacity to perform an amount of work during a specified period. When demand is compared to the capacity of resources, some will have a greater load than others. The process that is identified as having the greatest relative load will constrain the performance of the other processes in the factory and is identified as the factory capacity constraint.

Pull production ensures that work is properly scheduled to get the maximum performance from the factory capacity constraint while ensuring that it is customer demand that drives material flow through the factory. For each of the CP3 implementation projects pull production principles will be applied. The preferred control model is a system based on theory of constraints called ConWIP (Constant WIP), but depending on current factory production processes different control models may be used.

3.3.3 Supply Chain Integration

The implementation of lean practices should be applied not just to internal process, but also across the entire value chain. In order to increase overall efficiency, these internal practices must be linked with those of external suppliers to ensure that ABB factories are producing the best products at the best prices for their customers.

On time delivery from suppliers' ranges from 60 to 80 percent, yet ABB factories are striving for 100 percent on time delivery to their customers. In the past the late deliveries have been accounted for with higher inventories and longer lead times. This is a costly way to address the problem. By applying lean concepts to the value chain, waste can be eliminated and material purchasing can be optimized.

Supply chain integration is performed using a variety of lean tools including commodities analysis, kraljic matrix, value stream mapping.

3.4 Systems: Implementation Process

The Implementation Process used for implementing CP3 is based on ABB's "standard gate model," a tool used for product and technology projects within ABB. The model consists of "Gates" at different stages throughout the project, with criteria that must be met prior to progressing to subsequent stages. Review meetings or "Gate meetings," are held at the end of each stage and project progress is evaluated. Decisions on how to continue (e.g., cancel project, change scope, change plan) are made at each gate.

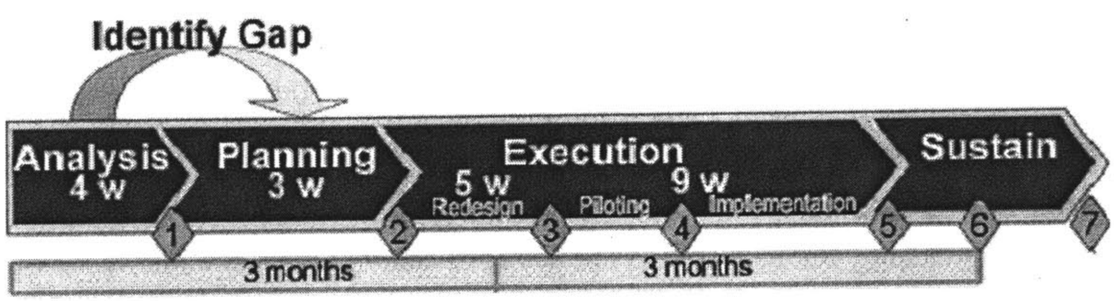

Figure 4: Phases of CP3 Including Time Durations

The implementation of a typical CP3 project takes between 6 and 8 months, depending on available resources and the factory condition. The implementation process is divided into four phases with the following estimated time durations:

- Analysis Phase – 4 weeks
- Planning Phase – 3 weeks
- Execution Phase– 3 months
- Sustain Phase – up to 3 months

3.4.1 Analysis Phase

The purpose of the analysis phase is to determine the current state of the factory and set future goals. The phase begins with an initial site visit to perform a feasibility study, assess the overall change readiness of the organization, and create a "current state" value stream map. The feasibility study [21] is performed using the CP3 Assessment Questionnaire, a discussion tool that helps to determine the factory's readiness to adapt to a CP3 implementation. The tool assists project leaders in benchmarking the factory, from a lean manufacturing perspective, and helps illustrate to the organization the benefits of lean techniques, where improvements in their operations can be made, where to focus the efforts, and how much change is needed. In conjunction with the feasibility study, a change readiness survey is administered to ascertain how equipped the organization is to contend with the many process and culture changes required to implement a lean manufacturing solution.

The most important part of understanding the factory's current situation is creating a current state value stream map. The value stream map visually shows how the product is built and documents the information and processes required to take a transformer from customer order to delivery of the product. The current state map is used to identify areas of waste and create a vision for the future. This future vision is documented on a "Future Value Stream Map" and serves as the basis for the project scope.

[21] ABB's feasibility study is explained in more detail in section 3.5.15

Once the scope is determined, the entire project is divided into separate "work packages" and lead individuals are identified for each package. These work package leaders form the core of the CP3 implementation team.

The first project review, or Gate 1 review, is performed when the project scope has stabilized and a feasible plan has been developed. The goal of the meeting is to review the project analysis phase and to obtain agreement on project scope.

3.4.2 Planning Phase

The purpose of the analysis stage is to define how the project will be executed based on the project scope. During this phase the project scope for each of the work packages is defined in detail including: Measurable Goals, Benefits, Scope, Work Package Tasks, Schedule, Resources and analysis of risks and risk mitigation. Using these defined objectives for each of the work groups, Key Performance Indicators (KPI) are established to monitor and set goals for each work package. The KPI goals are used to support a benefits calculation that forecasts the impact the CP3 implementation will have on future cash flows.

Teams comprised of factory workers are also created during this stage. Each team should have between 5 and 8 workers and is tasked with improving factory floor and continuous improvement projects.

The Gate 2 review should be performed when the project plan has stabilized. The review should assess the execution plan for each of the individual work packages and the overall project management plan. The outcome of the gate meeting is an agreement on the project plan and the feasibility of implementing the future factory vision using the selected tools. The gate meeting also serves to obtain commitment from all involved parties on the project.

3.4.3 Execution Phase

During the execution stage the focus is on implementation of the defined CP3 initiatives. This stage of the implementation is divided into three phases and has three gate reviews to monitor progress.

The first phase is intended to finalize the detailed redesign of new processes and implementation plan. During this step, processes are redesigned to support the "defined future state" requirements. A Gate 3 review meeting is held to review the proposed detailed implementation plans and is performed once all critical redesign decisions have been made. The outcome of the gate 3 meeting is an agreement on the design of the future factory.

The second phase marks the piloting of future operational processes. In order to gain an understanding for the success of the full-scale project, pilot projects are conducted to capture lessons learned and to refine the implementation plans. The pilots are limited in scale but with full functionality. Pilot results are reviewed to determine areas for improvement and lessons learned for the full-scale implementation. The Gate 4 review is performed once pilot project results have been successfully verified and are stable enough for validation and introduction onto the factory floor. The target outcome of the gate meeting is an agreement on the readiness for full process implementation.

The final phase of execution is the full-scale implementation of project. During this phase, performance should be regularly reviewed against the Key Performance Indicators selected during the planning phase. The Gate 5 assessment is held when the implementation of all major projects is complete. The target outcome of the gate meeting is a consensus that the major project implementations are complete, marking the start of continuous improvement.

3.4.4 Sustain Phase

Sustaining improvement is a fundamental part of running any successful factory. There is no such thing as a totally lean factory, hence lean manufacturing is a continuous and evolutionary process. Targets must continually be revised and factories must strive for continuous improvement, working to institutionalize the processes that advance lean manufacturing practices such as, further reducing waste, and continually monitoring progress. A factory can only be competitive in the long term if it can sustain a culture that continuously improves its processes. In order to sustain continuous improvement CP3 defines specific actions that should be taken.

Once the CP3 implementation is complete, work package owners assigned at the beginning of the implementation should continue to maintain responsibility for their work package area. As new processes are implemented, detailed process documentation is created to explain the process design and rules. In addition, once new processes are implemented, old systems are destroyed (where possible) in order to make it difficult to return to the old way of doing things.

Employees should be encouraged to use the non-productive time for Continuous Improvement activities. Tools such as work area improvement teams, 5S, visual factory, standard work sheets, error proofing and waste elimination should be used to improve factory processes. Employees should be regularly trained to promote waste reduction activities.

A plan should be created to regularly review implemented processes and factory performance (KPIs) and identify areas where future improvement efforts should be focused. Additionally, constant communication of the importance of continuous improvement and make the results transparent must be maintained.

Gate meetings are scheduled during the sustain phase to ensure that the implementation is continuing. A Gate 6 review is held once all project responsibilities have been transferred to the local factory and confirmation that the local factory has received all expected deliverables has been made. The outcome of the gate 6 meeting is closure of the implementation project. A few months following the Gate 6 meeting, a Gate 7 is held. This meeting is done when sufficient feedback on the new processes has been received from employees, suppliers, and customers. The outcome of the gate 7 meeting are documented lessons learned which are applied to future projects.

3.5 Tools: CP3 Tools

CP3 identifies a set of approximately 20 tools for use during implementation. Each of these tools has training and electronic templates that can be used by local factories to simplify their lean transformation. Each of these tools is a standard lean tool used in many companies; what is unique to CP3 is the selection and combination of tools.

The tools used in CP3 were selected based on previous lean implementations performed at factories around the world. Tools were chosen based on those which best fit the goal and culture of the company. The list of tools below is not meant to be a list of all the tools to be used. Neither is it meant to be a comprehensive list of the allowable tools. Instead, the tools selected for CP3 are intended to provide 25 tools that factories should focus on when implementing lean improvement systems.

3.5.1 5S

The purpose of 5S is to support continuous flow creation and lead-time reduction by better organizing workplaces and maintaining cleanliness. The name 5S originates from the five Japanese words describing the process to obtain an orderly workplace – Seiri, Seiton, Seiso, Seiketsu, Shitsuke. These works are translated as Sort, Straighten, Shine, Standardize, and Sustain. The implementation of 5S in the factory workplace allows workers to provide input in order to improve their own workplace. These improvements in organization, layout, and standardization lead to higher productivity, fewer defects, and a much safer workplace.

3.5.1 Assessment Questionnaire

The Assessment Questionnaire is part of the preparation phase of the Integrated Factory project. The focus of the questions is on the internal order-delivery process, but external factors are also taken into consideration. The assessment is a structured questionnaire, which helps to identify the development potential of a company's order-delivery process.

The assessment is designed to provide an understanding of the business and production environment the factory is operating in, the role the factory has in contributing to the company strategy, the challenges the factory is facing, and the gap between where the factory is and where the implementation of CP3 might take it.

3.5.2 Balanced Work Load

A balanced factory is one where all operations produce at the same cycle time and the cycle time is less than takt time. When cycle time[22] and takt time[23] are balanced, finished work units will come off the end of the line at the same rate that the customer demands them. A balanced work load helps make waste more visible and is a key step to creating one piece flow.

3.5.4 Benchmarking

Benchmarking is used to compare the competences of an organization with those that are considered 'best in class', in order to learn and improve performance. Benchmarking is a practical tool for improving performance by learning from best practices and the processes by which they are achieved. Benchmarking involves looking outward (outside your own company, organization, industry, region or country) to examine how others achieve their performance levels and to understand the processes they use. In this way benchmarking helps explain the processes behind excellent performance. When the lessons learned from a benchmarking exercise are applied appropriately, they facilitate improved performance in critical functions within an organization or in key areas of the business environment.

3.5.5 Benefits Calculation

A benefits calculation is intended to provide the projected cash flow improvements for implementing a CP3 project. Using a tool called Manufacturing Cash Doctor (MCD) it is possible to identify the cash flow improvement potential of a factory's order-delivery process. This tool uses historical inputs such as amount of cost of purchased material,

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[22] Cycle time is defined as the time it takes to complete an operation on a product.
[23] Takt time is defined as the rate at which customers demand a product.

revenues, gross margin, lead time, delay times, penalty fees, WIP levels, and inventory levels to determine a current baseline. Goals for the future are input including those for cycle time, WIP level, on time delivery, quality level improvements. Using both the historical data and projected improvements from the CP3 implementation, Manufacturing Cash Doctor will then calculate the future Cash flow impact. The tool demonstrates how improvements in manufacturing operations will affect the cash flow of the factory.

3.5.6 Cellular Manufacturing

Cellular layouts are a way of designing manufacturing processes next to each other so information, material and products can flow continuously. Cell shapes are dictated by space available in the production facility. Depending on the size and shape of the space to be used there are multiple shapes for cell layouts including S, U, L, and I. The most common shape is the U shape cell because it minimizes walking distances and allows for the most flexible work set up for operators. Cellular layouts have multiple advantages including lower WIP, reduced transportation distances, reduced waste of movement, and better quality feedback. The flexibility and simplicity of cells allows for more control and focus on the manufacturing process. Additionally the self-directed nature of cells creates a more motivated workforce.

3.5.7 Change Readiness Assessment Tool

The Change Readiness Assessment Tool is used to understand the change readiness of an organization. The change management questionnaire serves to determine the relative complexity of change for the location as well as the organization's change maturity. Each of the questions is weighted based on relative importance to both change complexity and change maturity. The resulting score provides the user with an idea of the overall change readiness of an organization. Once the questionnaire is completed, an implementation approach is proposed.

3.5.8 Commodities Analysis

In most manufacturing operations, the majority of the purchasing costs are spent on only a small number of parts. In order to ensure that the proper attention and effort is placed on the right types of parts a commodities analysis is performed. Parts are typically classified into three types depending on the annual amount spent on each.

"A" Parts: the first 5-10% of the parts that account for 80% of the annual purchasing expenditures

"B" Parts: the second 10-15% of parts accounting for 10 to 15% of the annual purchasing expenditures

"C" Parts: the bottom 80% of the parts accounting for only 10% of the annual purchasing expenditures

3.5.9 Communication Plan

CP3 will change the way people do work. The planned changes and reasons for changing need to be communicated to all involved. Various forms of communication should be used and a formal communication plan should be created at the beginning of the process. This plan should include various forms of communication such as meetings, reports, gate reviews, e-mail, newsletters and bulletin boards.

3.5.10 ConWIP

ConWIP (**Con**stant **W**ork **I**n **P**rogress) is a type of pull system, which limits and stabilizes the amount of work in process in the factory. Unlike traditional pull systems where the volume and speed are controlled by the following step and the overall production line is regulated by customer demand, in a ConWIP system orders are released based on the completion of a job at a defined control point.

The control point is a strategically selected process in the system to which all other manufacturing processes are subordinated. Once a job is completed at the control point a signal is sent to the beginning of the production line authorizing the release of the next job. Jobs flow through the production line from the beginning of the manufacturing process until the control point location along a constant routing structure. Once the job has passed through the single point control location, the remainder of the flow is controlled using FIFO (first in first out) methodology.

3.5.12 Error Proofing

"Error Proofing" is a method of systematically identifying sources of error and creating process to prevent there occurrence in the future. The goal of error proofing is to achieve ZERO defects by defining a process which strives to create quality from the source and ensures that defects are not passed on to downstream customers. The three major principles of error proofing are to implement devices to prevent operators from making mistakes, provide immediate feedback to detect errors when they occur, and inspect material to ensure defects are not passed downstream. In order to implement these principles it is important to understand the cause of errors through problem solving and develop changes to ensure that they do not happen in the future. Common sources of errors include environment, measurement, human, machine, material, and method errors. Any of these factors, alone, can cause a defect, but normally, defects are caused by a combination of sources.

3.5.13 Factory Capacity Constraint

Determining the factory capacity constraint means finding the process that limits a factory's production pace; i.e.,a factory production line is only as fast as its slowest process; therefore, the slowest machine in the process determines factory throughput. It is important to understand where the factory capacity constraint exists because an hour lost at that process is an hour lost for the entire factory. Because this process sets the throughput for the factory, if the process stops, it is equivalent to stopping the entire factory.

3.5.14 Factory Layout

A key aspect of CP3 implementation is improving the flow of products. One tool used to accomplish this is changes to the factory layout. Ideally, process steps should be located immediately adjacent to each other so that parts and information can be easily handed off from one process to the next. When designing a new factory layout one of the primary objectives should be to minimize transport distances. Minimized transport distances lead to reduced handling costs, increased communication, and help enable continuous flow.

3.5.15 Feasibility Study

The CP3 Feasibility Study is performed using an assessment questionnaire. The focus of the questions is on the internal order-delivery process, but external factors are also taken into consideration. The assessment is a structured questionnaire, which helps to identify the development potential of a company's order-delivery process. Questions are grouped under six different categories: strategic focused factory role, sales and quotation process, engineering process, production processes, supply chain management, and change management

The assessment is designed to provide an understanding of:

- The business and production environment the factory is operating in
- The role and contribution of the factory to the BA strategy
- Challenges the factory is facing in operations management/development
- The gap between current processes and the CP3 "main practices"

3.5.16 FIFO

FIFO (First in First Out) is a production sequencing method that ensures that the first part to enter a process or assembly queue will be the first part to leave the process. In order to create continuous flow a FIFO process must be used. Manufacturing flow that allows older material to be placed in inventory while recently produced inventory is processed leads to long-term problems with part storage and obsolete parts.

3.5.17 Kanban

Kanban is a signal device used to provide the authorization for production in a pull system. A kanban system is used to manage the flow of material so that products are produced only when the customer demands a product. Kanbans have two main functions in a factory: they signal process to make products and they signal material handlers to move products. Kanban signals that authorize processes to make products are called

Production Kanbans. These Kanbans are used to instruct upstream process to make products for downstream processes. Kanbans that authorize the movement of parts to a downstream process are called Withdrawal Kanbans. These signals can be used to trigger production either at internal processes or at supplier locations.

3.5.18 KPI Monitoring

Key Performance Indicators (KPIs) are used to monitor performance over a period. The use of KPIs provides a link between the factory floor and upper management by helping everyone understand how well the company is performing. For the CP3 implementation several key KPIs were chosen to monitor during the project implementation so project progressing could be understood. Once CP3 implementation is complete, KPIs are continuously monitored in order to encourage continuous improvement

CP3 KPIs are:

1. Throughput Time (TPT)
2. Total Throughput Time (TTPT)
3. Work In Progress (WIP)
4. On Time Delivery (OTD)
5. Cost of Poor Quality (COPQ)
6. Inventory (raw material, finished goods)
7. Employee Satisfaction
8. Supplier On Time Delivery (OTD)

3.5.19 Kraljic Matrix

The Kraljic Matrix is a method used to analyze factories purchasing portfolio methods. The matrix classifies products based on two dimensions: impact to profit and supply risk. The result is a 2x2 matrix dividing products into four classifications: bottleneck, non-critical, leverage and strategic items. Using a Kraljic Matrix allows for categorization of parts into and leads to identification of optimal purchasing plans.

3.5.20 Process Time Study Sheet

Process times study sheets are used to capture the build processes currently used in production. In order to collect the data for process time sheets members of the CP3 implementation team observe the production process. Once the process time study is complete the information is used to analyze the detail production process and identify which parts of the process add value and which are waste.

3.5.21 Project Execution Plan

The Project Execution Plan describes the process which will be used to achieve the agreed on project scope. Each of the individual work packages defined in the Project Scope Agreement is detailed to include

1. Measurable goals for each work package
2. Benefits
3. Scope
4. Sub work packages
5. Work Package Tasks
6. Work Package Schedule
7. Resources
8. Analysis of Risks and mitigation

Using the defined objectives for each of the work packages, the Key Performance Indicators (KPI) are selected and goals for future performance are set. These future performance goals are used to predict future cash flow improvements using the Benefits Calculation Worksheet.

3.5.22 Project Scope Agreement

The Project Scope Agreement defines and documents the project scope for CP3 implementation at a specific factory. It documents the current processes in place and identifies major areas for improvement noting the proposed solution and expected benefits. In the document, the project scope is broken down into individual work packages identifying key project leaders for each area.

3.5.23 Standard Work Sheet

Standard Work Sheets are used to display the work procedures and general work area layout for each of the areas of a factory. The work sheet documents the parts required for a job, factory takt time, workstation cycle time, the sequence of work elements, and safety procedures. They are used in areas where the process is defined and repeatable. The work sheets are used as a foundation to identify areas of improvement. By evaluating actions, procedures can be reordered to prevent problems and waste can be identified and eliminated.

3.5.24 Supermarket

Supermarkets are areas where inventory is stored to supply downstream processes. Each part in a supermarket has a specific location where parts are stored. Once parts are removed a signal is sent to the supplying process to make more of the product. The number of parts held in a supermarket is limited and once this quota has been reached the production process used to supply it are stopped.

3.5.25 Value Stream Mapping

A value stream map shows how a product is built identifying all the actions necessary to design, order, manufacture, and deliver a given product. It shows the flow of materials, the transformation of raw materials through manufacturing processes, and the flow of information. By identifying and understanding the value stream, steps can be identified which do not add value to the customer. The analysis of the value stream map defines the scope for the project.

3.5.26 Visual Factory

Visual factory is a simple and highly successful lean-production approach that uses visual indicators, signals, and controls to direct and support activities on the shop floor. The result is a self-explaining and self-regulating workplace where critical information is shared rapidly, accurately, and without speaking a word. In a visual factory the whole workplace is set-up with signs, labels, and color-coded markings, such that anyone unfamiliar with the process can, in a matter of minutes, know what is going on, understand the process, and know what is being done correctly and what is out of place. The result is a clear work process that makes it easy to do the job right.

3.5.27 Waste Identification and Elimination

At the heart of lean implementation is the identification and elimination of waste. Waste is identified as any activity that the customer is not willing to pay for, including things such as waiting times and rework. In most factories, the ratio of waste/value is 95/5. Waste does not create value and must be eliminated for operations to become effective.

There are 7 wastes defined in lean production:

1. Over Production
2. Waiting
3. Transportation
4. Excess Processing
5. Excess Inventory
6. Excess Motion
7. Quality Defect

3.6 Evaluation: CP3 KPI's

ABB has created a set of KPI's for analyzing the overall operations performance level of factories. Seven KPIs are used to monitor factory performance.

1. Throughput Time (TPT)
2. Total Throughput Time (TTPT)
3. Work In Progress (WIP)
4. On Time Delivery (OTD)
5. Cost of Poor Quality (COPQ)
6. Inventory (raw material, finished goods)
7. Employee Satisfaction
8. Supplier On Time Delivery (OTD)

Chapter 4. Lean Manufacturing Activities at Monselice, Italy

4.1 Factory Background

The ABB Monselice factory produces liquid filled distribution transformers (5MVA – 40MVA, up to 72.5kV). The factory produces approximately 300 per year for markets in Europe, the Middle East, and Northern Africa. The factory was originally established in 1952 and operates with 128 employees including 68 labor and 60 engineering and staff.

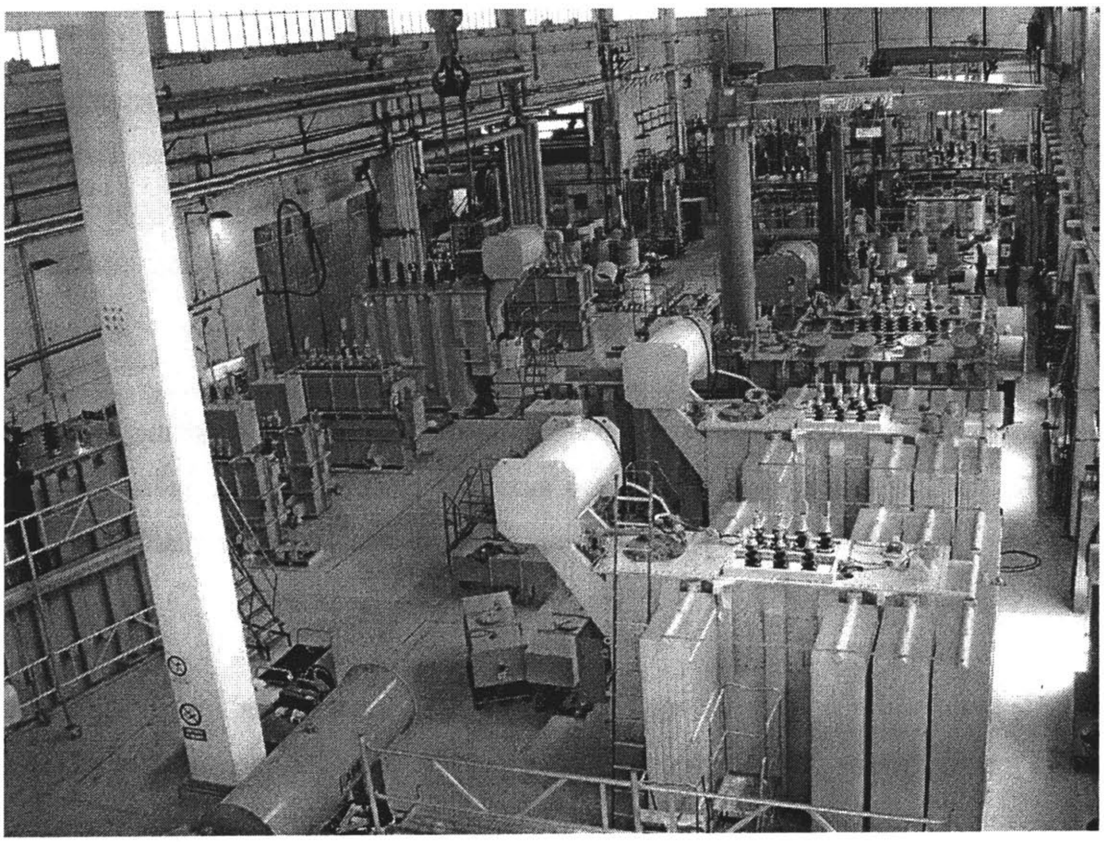


Figure 5: Monslice, Italy Production Line

The transformers are standard components for power distribution substations and are also used by power generating plants, refineries, and desalination plants. The market for the product is divided into three distinct segments: Engineering Procurement Contracts, Utility Companies, and Industry. Most of these products are specific customer specified designs and are engineered to order (ETO).

4.2 Factory Processes

Production begins with the winding process that creates the high voltage, low voltage and regulation windings for each transformer. Monselice uses 4 types of winding technologies including foil, multilayer, CTC and disc winding. The multilayer, CTC and disc windings require that a clamping and drying process be completed prior to assembly. Once the windings have been completed, they are taken to the assembly area.

Assembly has the longest individual process time in production, ranging from 70 to 300 hours based on transformer type. Once assembly operations are complete, the "active" components (core, winding, yoke and cover) are lifted into the tank and transported to the drying area. Drying is performed to remove moisture from the active parts. The process takes approximately 48 to 72 hours using either a Low Frequency Heating process or a large oven. The total capacity of this process is 1 transformer per day making this process the capacity constrained resource for the plant.

Once the drying process is complete, the transformers are moved by crane to finishing where the tank is filled with oil and the auxiliary electric circuits, radiators and oil conservator are assembled. The finishing process takes approximately 80 hours, performed over three shifts

After the transformer is fully assembled, it is moved by crane to the testing area. There are two testing stations, one for regular testing and the other for special types of testing. Testing times range from 1 to 5 days depending on transformer type and customer requirements.

After testing, the transformer is again moved by crane to the shipping area. Before the transformer can be shipped the conservator, fans, radiators, and often bushings and other sensitive components are disassembled.

4.3 Identified Areas of Opportunity:

4.3.1 Excessive Levels of Work In Progress

Work in Process levels in the factory were higher than necessary. New orders were pushed onto the floor based on schedules and the scheduling process included no constraints to limit the amount of work in process. As Little's Law explains, when the amount of Work in Process is increased, the total throughput time for the order is also increased. As the amount of WIP on the floor increased, the total average throughput time increased. Due to space constraints in the factory, carrying excess inventory led to congestion in the work areas.

4.3.2 Product and Process Time Variability

All products in the Monselice factory go through the same order, manufacturing and delivery processes. Due to the wide range products the cycle times on both production and non-production processes is highly varied. This high variation in lead times makes scheduling production difficult; as a result, the variation was buffered by inventory, protective capacity, and increased lead time.

4.3.3 Long Pre-Production Processes

Much of the product lead time occurs during pre-production processes such as engineering, order confirmation, drawing approval, and customer confirmation. The total product lead time is 24 weeks, of which 17 is consumed by pre-production processes.

4.3.4 Lack of Integration in the Supply Chain

Prior to CP3, supplier on-time delivery was approximately 75%. In addition, supplier lead times were longer than the lead times projected for the post CP3 preproduction processes. Although supplier processes were understood at a high level, lead time drivers, and how they could be reduced, were not well understood.

4.3.5 Workplace Housekeeping

Many areas in the factory were not optimized to perform the required work. In the warehouse, for example, material was stored on a space available basis often making it difficult to find the required parts. Many of the commonly used raw materials were also stored in the warehouse instead of on the factory floor, at point of use. In the work cells common tools were stored in individual work carts and other items were not clearly labeled or consistently stored in the same location. Other unneeded items such as excess equipment and inventory were kept on the factory floor taking up valuable space.

4.3.6 Push based Production Scheduling

Production control in the Monselice factory was performed using a scheduling program. The aim of scheduling was to achieve high utilization of each operation, but due to the high variability in the factory processes, efficient execution of this strategy was difficult. The scheduling for a single order was performed in three different "layers" over the course of two months. Depending on the status of the factory floor, frequent re-scheduling was performed.

4.3.7 Lack of Material and Information Flow

Material and information flow on the factory floor was not optimized for production. Raw materials were delivered to the work place by the area supervisors based on their availability and understanding of where the transformer was in the manufacturing process. Transformer movement from one processing area to the next was based on a layout built around an awkward facility shape and crane layout. Information flow about what job to process next, the sequence of production steps, and how to process paperwork was not clearly defined or handled in a consistent manner.

4.4 Executed Changes

Prior to the CP3 implementation the Monselice factory had implemented several change initiatives, but still lacked a coherent focus for production control, continuous flow, and supply chain integration in the factory. Individual projects had been undertaken to optimize production in several areas, but few had looked at the factory as a whole. While the factory performance was acceptable, it was not at a level high enough to sustain competitive advantage. Factory management was being pressed by both customers and ABB corporate to reduce costs and delivery times.

The CP3 process began in February when both PTDT management and CRC employees visited the factory. The purpose of this visit was to understand the current state of operations in Monselice and to determine whether Monselice was a fitting pilot location for CP3 implementation.

4.4.1 Feasibility Study and Change Readiness Assessment

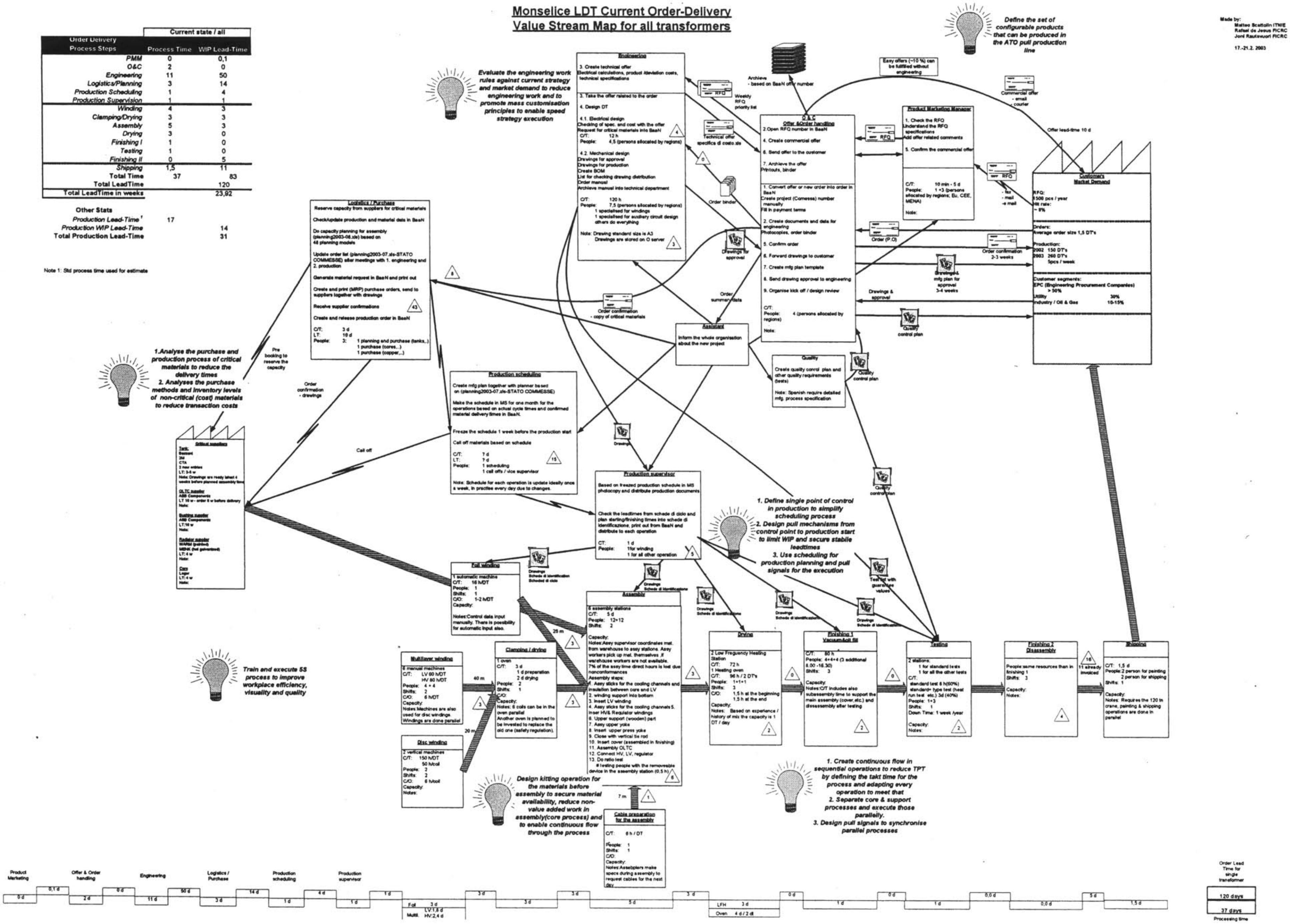
In order to understand the current state, feasibility study and change readiness assessment were performed. Based on the results of both of these studies it was decided that Monselice would be a good candidate for the pilot CP3 implementation because of its supportive management and the opportunity for large impact changes in a short period.

4.4.2 Value Stream Mapping

The implementation team analyzed factory processes using value stream mapping techniques based on data gathered during a factory "walk-around". Throughout the tour, process related information was gathered using various techniques, such as interviewing, observation, and document review. During this process a basic "current state" value stream map was sketched out using inputs from both workers on the factory floor and those on the team. The results of the value stream mapping exercise are shown in Figure 6.

Using the current value stream map, the overall factory processes were reviewed to determine "high level" improvement areas. The entire group reviewed the current state map and brainstormed opportunities to reorganize, reduce work elements, simplify processes, reduce costs, decrease variability and drive towards a more lean factory. The ideas for improvements included the following:

- Evaluate engineering work to promote customization principles
- Define a set of configurable products
- Define a single point of control in production to simplify scheduling



	Current state / all	
Order Delivery Process Steps	Process Time	WIP Lead-Time
PMM	0	0,1
O&C	2	0
Engineering	11	50
Logistics/Planning	3	14
Production Scheduling	1	4
Production Supervision	1	1
Winding	4	3
Clamping/Drying	3	3
Assembly	5	3
Drying	3	0
Finishing I	1	0
Testing	1	0
Finishing II	0	5
Shipping	1,5	11
Total Time	37	83
Total LeadTime		120
Total LeadTime in weeks		23,92

Other Stats

Production Lead-Time [1]	17	
Production WIP Lead-Time		14
Total Production Lead-Time		31

Note 1: Std process time used for estimate

Figure 6: Monselice Current State Value Stream Map

- Create continuous flow in sequential operation
- Execute 5S to improve workplace efficiency
- Design kitting operations for assembly

After analyzing the current state and brainstorming future improvement, a "future state" concept map was created showing the future state vision for the CP3 implementation. The new future vision included the implementation of a ConWIP system, a less complicated pre production process, and the division of the manufacturing process into standard and highly customized transformers. The future state value stream map is included in Figure 7.

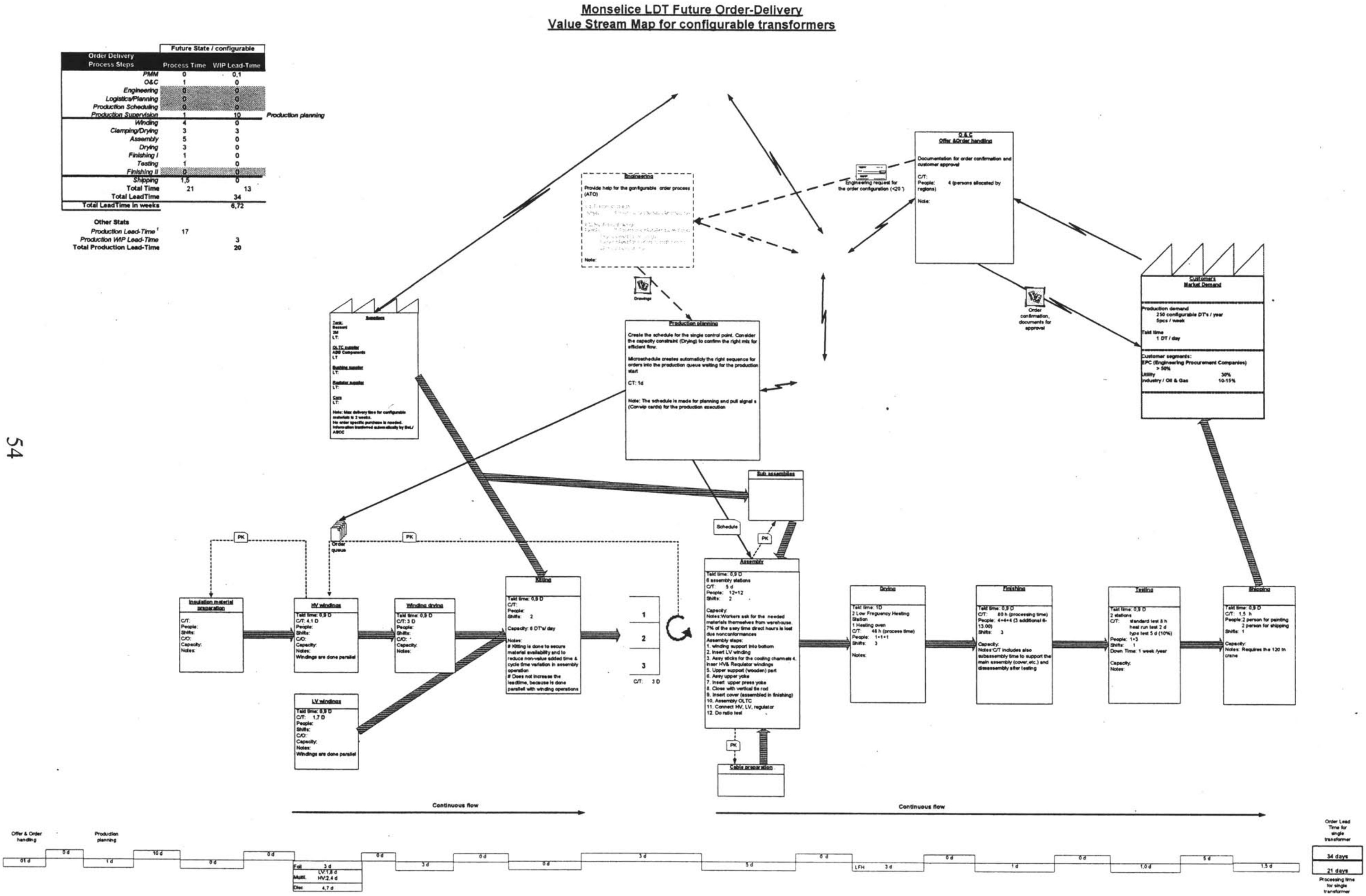
4.4.3 Benchmarking

A benchmarking trip to the Finnish ABB factory was made by local project focal and trips to local ABB factories were planned for the 5S teams so that the benefits of lean implementation could be witnessed first-hand by employees. CP3 training session requirements were identified and basic training was performed on two levels, one for the upper and middle management and another for factory workers. Because most factory workers do not speak English, training was contracted to an external provider who was better equipped to communicate the purpose and process for implementing 5S and lean manufacturing.

4.4.4 Key Performance Indicators

In order to track the progress of changes, Key Performance Indicators (KPI) were defined for the CP3 implementation based on the defined project objectives. Most of the KPIs were existing business KPIs and already tracked in the operational database. Two new KPIs were added to track the 5S housekeeping index and employee satisfaction. For each KPI, targets were set for three different windows; July 2003, year end 2003, and year end 2004. These targets were further divided into red line and green line products.[24] The initial KPIs and targets for Monselice are shown in Figure 8.

[24] Green line products are standardized products and red line products are custom products



Order Delivery Process Steps	Future State / configurable: Process Time	WIP Lead-Time	
PMM	0	0,1	
O&C	1	0	
Engineering	0	0	
Logistics/Planning	0	0	
Production Scheduling	0	0	
Production Supervision	1	10	*Production planning*
Winding	4	0	
Clamping/Drying	3	3	
Assembly	5	0	
Drying	3	0	
Finishing I	1	0	
Testing	1	0	
Finishing II	0	0	
Shipping	1,5	0	
Total Time	21	13	
Total LeadTime		34	
Total LeadTime in weeks		6,72	
Other Stats			
Production Lead-Time [1]	17		
Production WIP Lead-Time		3	
Total Production Lead-Time		20	

Figure 7: Monselice Future State Value Stream Map

KPI	% Improvement 2003	2004
Manufacturing Throughput Time (TPT)	38%	45%
Total Throughput Time (TTPT)	19%	38%
Work in Process Levels (as % of revenue)	63%	68%
On Time Delivery	36%	39%
Cost of Poor Quality	50%	69%
Inventory (as a % of revenue)	22%	38%
Supplier On Time Delivery	27%	33%

Figure 8: Monselice Key Performance Indicators (KPIs)

Using the Manufacturing Cash Doctor tool[25] the projected cash flow improvements of the operational changes were calculated. Historical data and projected improvements from the CP3 implementation were input into the tool to calculate the future cash flow impact.

4.4.5 Implementation of ConWIP Production Control System

The creation of an improved production control system began with a high level analysis of the factory to determine the factory capacity constraint. Using the results from the value stream mapping exercise, a simulation was created to model the factory processes, confirming drying as the factory capacity constraint.

Once the factory constraint was identified and confirmed, new control models were reviewed. Other factories at ABB had implemented ConWIP systems with success and it was decided the ConWIP control model would also work well in Monselice because of its simplicity and the focus it places on identifying the factory capacity constraint. Since the drying process was the constraint, it was selected as control point for the ConWIP implementation.

[25] See section 3.5.5 for additional details

The next step was to determine the details of how the ConWIP system would function. One of the major tasks was to understand how information would function in the new system. The most important part of the information flow was determining how the ConWIP signal would be communicated; in the end, a simple red envelope was chosen. When a job is completed at the control point, this envelope is sent to the beginning of the assembly line to signal that a new job can be started. A new visual way to display the sequence of upcoming jobs also needed to be developed. A board to display this information was fabricated and placed in a central location in the winding area. The board was designed with slots that hold the required transformer information including the drawings and quality assurance paper work required to build the part.

As Mark Spearman et al (1990) recommend initial ConWIP levels were set higher than optimum and will be lowered over time. The initial ConWIP level for the start of the implementation was set to 30 transformers with a target of achieving 25 transformers within the first quarter. Long term target for ConWIP levels have also been computed. The details of these calculations are included in Appendix A.

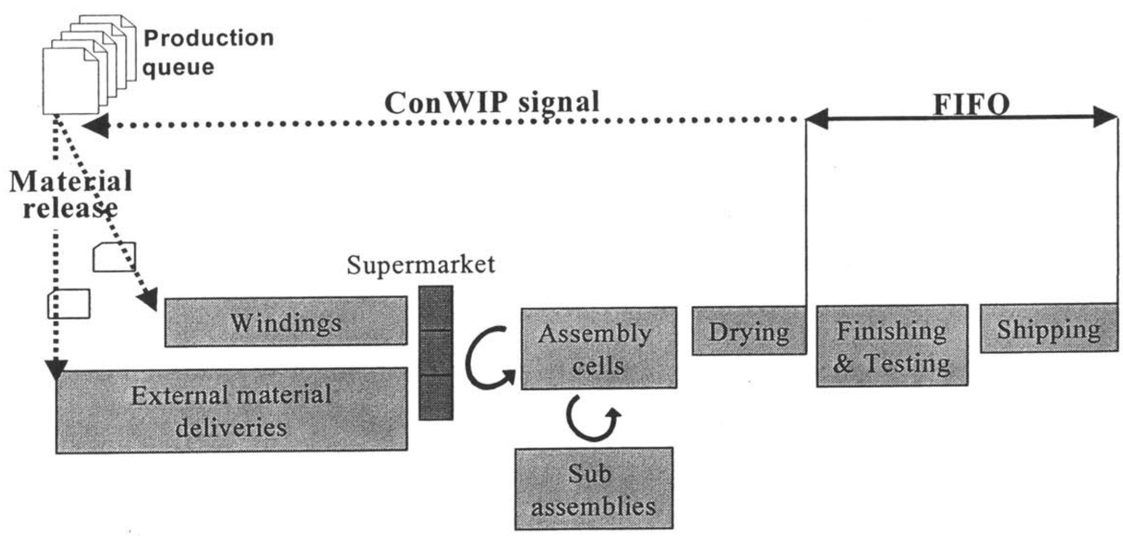


Figure 9: Monselice Application of ConWIP

Once the ConWIP system was designed and operators understood the process to be used, a ConWIP pilot was implemented. Although WIP levels were kept higher than the long term targets, the full process, including the new information flow, was implemented. During the first few weeks, the process was carefully monitored to ensure that no orders started without first receiving a ConWIP signal. The pilot implementation proved to be successful.

The factory is currently working to transition to the improved WIP levels specified under the CP3 targets. Implementing ConWIP in the factory has helped to improve the understanding of the importance of WIP levels on the factory floor. It has also placed emphasis on understanding the factory capacity constraint and working to make certain that the proper attention and focus is placed on ensuring that it is properly operating.

Since ConWIP has been implemented the sequence of upcoming orders are now clearer and workers on the factory floor have a better understanding of what the work flow is. As time passes and the process is improved, it is expected that WIP levels can be further reduced, leading to reductions in throughput times. Appendix A details a model created for analyzing variations in cycle times to set future WIP levels.

4.4.6 Creation of Pre-Production Milestones

As part of the CP3 implementation, the pre-production process was redefined to include a series of milestones. These milestones were titled Order Realization (OR) points. Weekly Planning meetings with the entire organization were instituted to ensure discussion of pre-production activities and that the milestones were being met.

The first milestone (OR1) is the order realization milestone. In order to pass this point and move into the next phase of the design process, preliminary planning and the electrical design must be completed. The second milestone (OR2) marks the completion of the mechanical engineering design, the third milestone (OR3) is passed once the purchasing has been completed and the final milestone (OR4) marks the completion of the preproduction process. At this point, the schedule and design are frozen and further changes are not permitted without management approval.

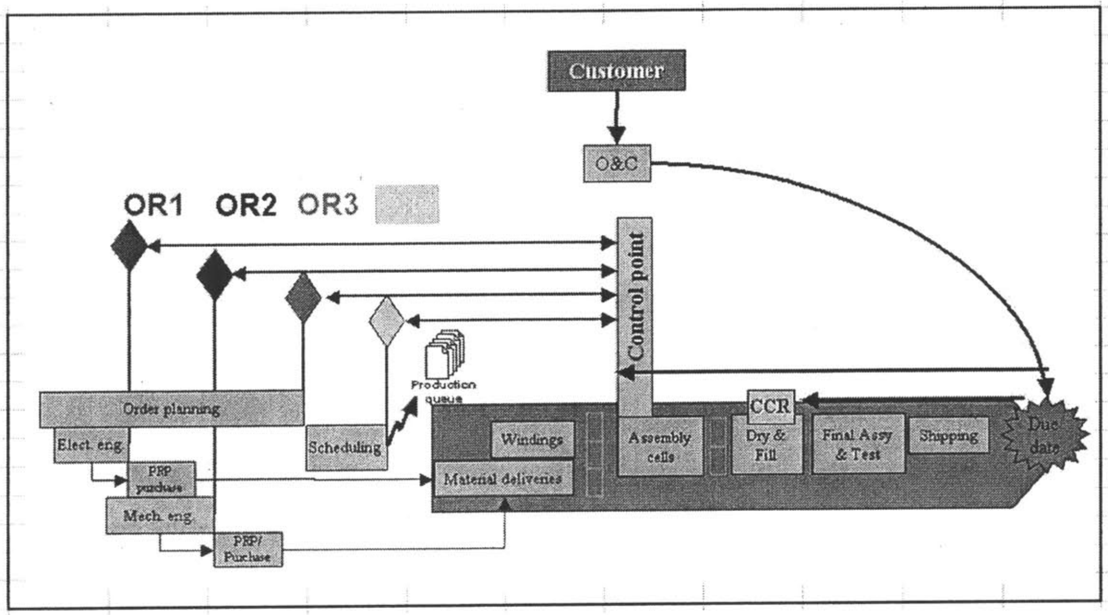


Figure 10: Monselice Pre-Production Milestone Process

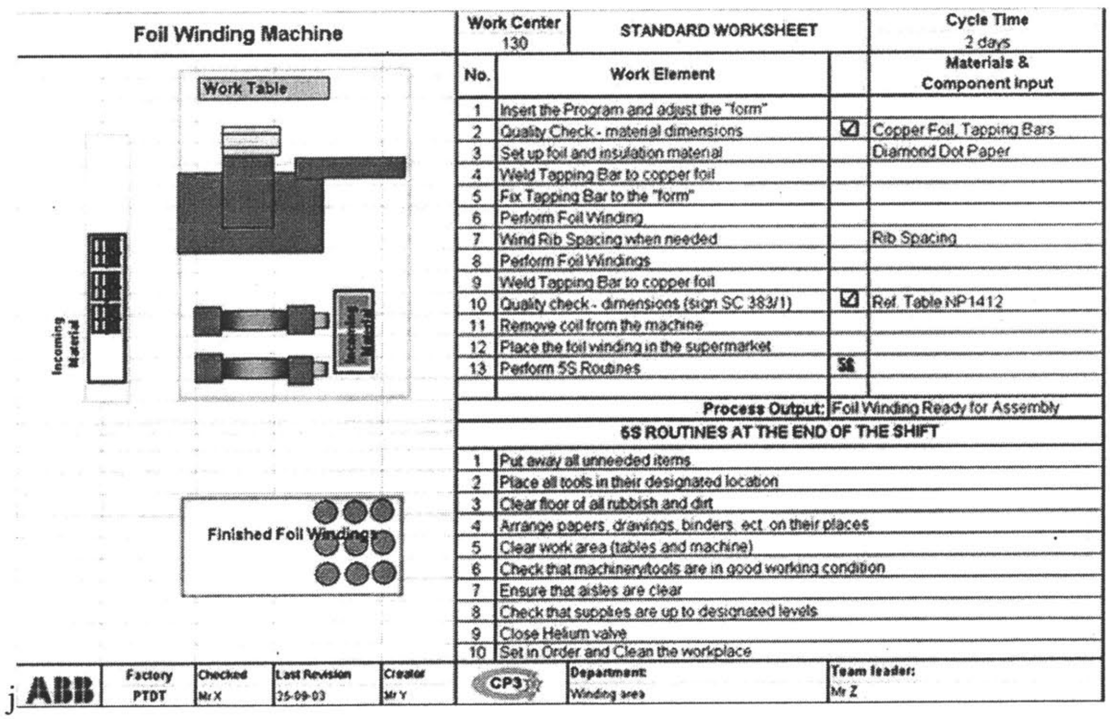
The creation of an order realization milestone model instituted a framework that prevented incomplete transformer designs from being passed down the process. As mentioned in section 4.3, Identified Areas of Opportunity, many problems in the pre production processes, prior to the implementation of CP3, stemmed from incomplete or incorrect product definition being passed downstream.

4.4.7 Continuous Flow Study

Each of the major areas of the factory was observed in order to perform process time studies. Each step in the process was documented including the time required to perform each step. Each of the observations were scrutinized for waste and a careful review revealed that much of the time spent during the manufacturing processes was not spent on value added activities, such as creating the windings, but on gathering information and materials.

Using both factory floor observations and the data gathered in the value stream mapping exercise a flow analysis of the current factory layout was performed to determine transport distances. Based on this information, new proposals for factory layout were reviewed so that products and people could move through it efficiently to perform the required work. In Monselice, many barriers existed to implementing ideal solutions due to the unusual shape of the factory and the crane routings. Working with these limitations a new interior layout with improved flow was created. The most important changes were the creation of dedicated work cells for each of the major areas, a new warehouse layout, and the creation of an alternate transformer transportation system using a tractor and trolley.

Using the information gathered during process time studies, preliminary versions of standard work sheets were created. Each of the work cells in the factory has a standard work sheet and the most efficient work procedures, safety processes, quality checks, layouts and 5S procedures are defined for each of the processes. An example of a standard worksheet is shown in Figure11.



Work Center 130	STANDARD WORKSHEET		Cycle Time 2 days
No.	Work Element		Materials & Component Input
1	Insert the Program and adjust the "form"		
2	Quality Check - material dimensions	☑	Copper Foil, Tapping Bars
3	Set up foil and insulation material		Diamond Dot Paper
4	Weld Tapping Bar to copper foil		
5	Fix Tapping Bar to the "form"		
6	Perform Foil Winding		
7	Wind Rib Spacing when needed		Rib Spacing
8	Perform Foil Windings		
9	Weld Tapping Bar to copper foil		
10	Quality check - dimensions (sign SC 383/1)	☑	Ref. Table NP1412
11	Remove coil from the machine		
12	Place the foil winding in the supermarket		
13	Perform 5S Routines	5S	
	Process Output:	Foil Winding Ready for Assembly	

5S ROUTINES AT THE END OF THE SHIFT	
1	Put away all unneeded items
2	Place all tools in their designated location
3	Clear floor of all rubbish and dirt
4	Arrange papers, drawings, binders, ect. on their places
5	Clear work area (tables and machine)
6	Check that machinery/tools are in good working condition
7	Ensure that aisles are clear
8	Check that supplies are up to designated levels
9	Close Helium valve
10	Set in Order and Clean the workplace

ABB	Factory	Checked	Last Revision	Creator	CP3	Department:	Team leader:
	PTDT	Mr X	25-09-03	Mr Y		Winding area	Mr Z

Figure 11: Monselice Standard Worksheet

The worksheets are placed in visible areas in each of the workcells. They are used for general employee reference, new employee training, timing raw material delivery, and to explain factory processes to visitors. As part of the ongoing improvement process the standard worksheets will be audited to ensure that operators are following the documented work processes. In some cases deviations from work processes will occur because employees are not properly trained, in other instances employees may discover more efficient ways to accomplish the work.

4.4.8 Deployment of 5S

In order to show employees first hand the impact a 5S implementation can have on a work place, a pilot area was chosen. The service area was selected because it provided an opportunity for large improvements that could be made rapidly. As shown in the pictures below, the 5S implementation in this area was very successful.

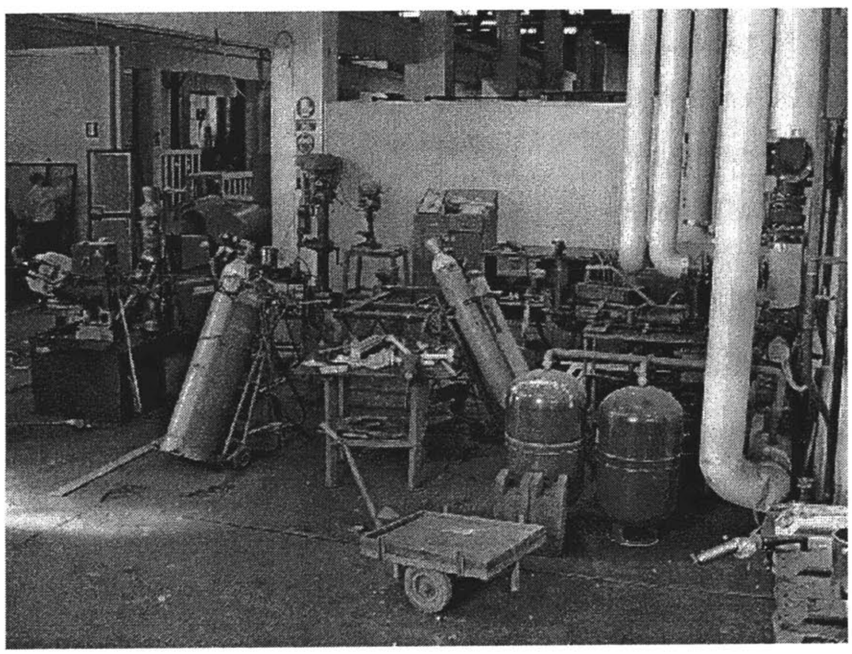


Figure 12: Monselice Service Area BEFORE 5S Implementation

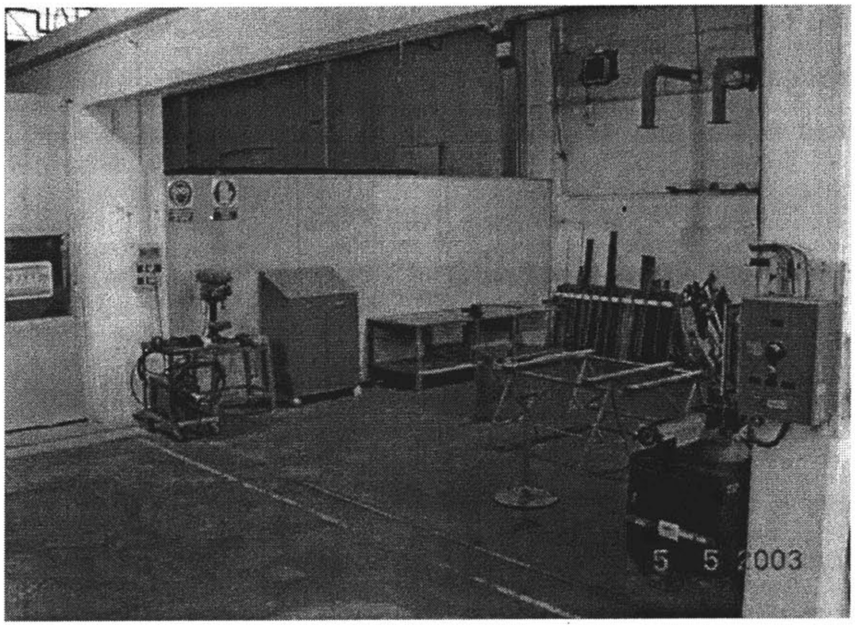


Figure 13: Monselice Service Area AFTER 5S Implementation

Once the implementation in the pilot area was completed, the 5S implementation was started throughout the factory. The implementation was phased using the 5 stages of 5S: Sort, Set in Order, Shine, Standardize, and Sustain.

In order to ensure that improvements made in the workplaces are sustained in the future a variety of steps were taken to ensure that the 5S practices were standardized into everyday work processes. Examples of this include the creation of weekly audit lists, 5S level criteria, and future targets for 5S levels.

The implementation of 5S processes in Monselice has allowed employees to provide creative input on improving their workplace. The results, according to one of the Monselice employees is "...a more pleasant work place with standard ways to organize material."

4.4.9 Creation of a Visual Factory

In conjunction with the 5S implementation, focus was placed on creating a visual workplace. Many changes such were made across the factory. In the warehouse, new shelf labels were created with holders for shipping documentation, across the factory information boards were created and updated showing the progress of the CP3 implementation and other important department information. In the work areas, floors were painted to mark cell boundaries, incoming material locations and finished goods locations.

4.4.10 Division of Product into Product Lines

One major improvement identified, but not yet implemented was the division of Monselice products into separate product families. The lines are planned to be called the red line and the green line, where green line products are standard distribution transformers and red line products are more specialized. Under the product division plan the transformers will be produced on separate manufacturing lines. By dividing the products into separate lines the amount of variation in processing times can be reduced. Additionally the customers of green line products are offered the added benefit of a lower cost product with faster delivery times.

4.4.11 Integration of the Supply Chain

During the analysis phase a basic supply chain assessment was performed and the internal processes were mapped using value stream mapping techniques. In order to determine which commodities to focus the improvements on a high level commodities analysis was performed. Each major part required for production was reviewed to determine whether current lead times could meet future requirements. This analysis helped the team understand the important parts to focus on.

In order to reduce supplier lead times, opportunities for part standardization were reviewed with engineering. Multiple parts such as bushings and tap changers were identified as candidates for standardization. Together with the supplier, engineering and the supply chain manager new product standards were created.

Pilot implementations have successfully occurred with some of the new supply chain processes, but full implementation will not occur until the rollout of the first greenline product.

The results of the supply chain integration project are impressive. Although hard to quantify, perhaps the largest benefit is an increased understanding of supplier processes. Easier to quantify are the benefits of the reduced lead times on critical components. Using a combination of part standardizations and strategically placed raw material, significant inventory delivery lead time reductions have been achieved; e.g., radiator lead time was reduced from 20 days to 10 days, tap changers from 50 days to 20, copper from 20 days to 12 days, and tanks from 20 days to 14 days. Future goals for the continuous improvement of supply chain integration include working to reduce inventory levels, continuing to reduce supplier delivery times, and improving on time delivery rates.

4.5 Sustaining Changes Made

Monselice is now in the sustain phase of its implementation. Work package owners who were assigned at the beginning of the process now fully own the on going continuous improvement of those areas. All of the employees were trained, and the systems have been communicated and documented. 5S teams and local factory resources are continuing to look for areas to improve using the tools learned during the CP3 implementation such as 5S, visual factory, error proofing and waste elimination. KPIs are reviewed on a monthly basis to track the process of factory performance and ongoing changes. The changes implemented during the CP3 project are having an impact and can be seen in the KPI numbers graphed below.

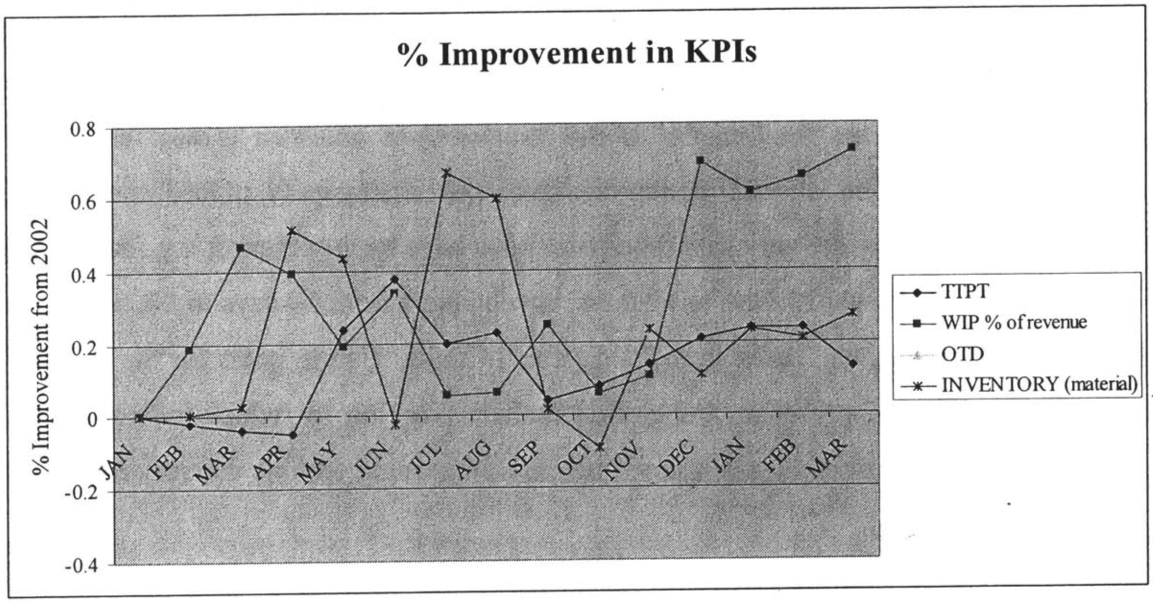


Figure 14: Monselice Key Performance Indicators Update

Chapter 5. Lean Manufacturing Activities at Zaragoza, Spain

5.1 Factory Background

The ABB factory in Zaragoza, Spain manufactures vacuum cast coil transformers rated up to 25 MVA. The factory produces approximately 3000 units per year for markets in Europe, Africa and the Middle East. The factory was built in the 1950's and employs approximately 160 employees.

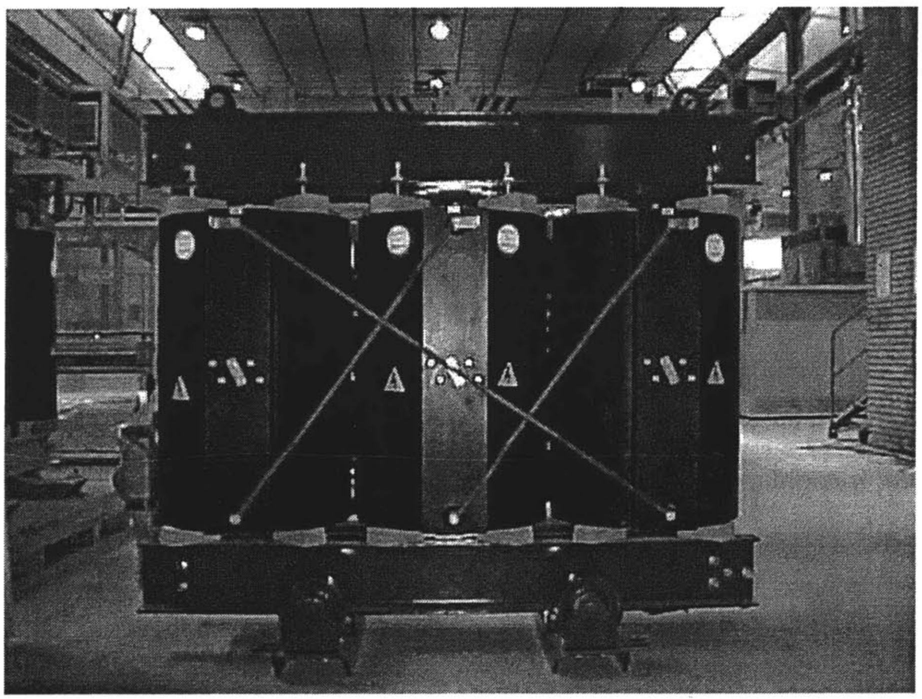


Figure 15: Typical Distribution Transformer Produced by the Zaragoza Factory.

Vacuum cast coil transformers are used in applications where customers need to minimize environmental contamination and fire hazards. The transformers are water proof and capable of withstanding rolling and vibration. These characteristics make them ideal for operation in extended range applications such as windmills, marine applications, metros (subways), and airports.

5.2 Factory Processes

The vacuum cast coil transformers are built up using three main subassemblies; core, high voltage (HV) windings and low voltage (LV) windings. In the Zaragoza factory each of these subassemblies is manufactured on a separate line.

The core of the transformer consists of multiple layers of magnetic steel. The process to build up the core begins with the slitting operation that takes the rolled magnetic steel raw material and cuts it into the required width. Once cut to width, the material is then taken to the core cutting area where the metallic steel is cut to the proper length. The next step, stacking and clamping of the core is primarily outsourced to a local supplier. Once the supplier has completed these processes, the completed core assembly is returned to the factory for assembly.

The first step in the process to create the high voltage (HV) windings is the winding operation. HV windings are typically wound using foil strip or wire and are then placed in a mold and sent through the vacuum casting process that preheats, casts, and cures the assembly. The entire casting process takes approximately 18 hours. Once the windings have been allowed to dry, they are removed from the mold and are ready for assembly.

The low voltage (LV) windings are built up by winding foil and pre-impregnated material together. The average cycle time for the winding phase is 4 hours. Once this is complete, the winding must cure for approximately 4 hours prior to assembly.

The HV windings, LV windings and cores progress to the assembly area where the windings are placed around the core on supporting blocks and are assembled with other accessories such as temperature indicators, information plates, wheels, tap changers, anti-vibration pads, to complete the build up of the transformer. The assembled transformer is then taken to the testing area to perform tests that ensure the product meets customer specifications. Once testing is complete a final paint touch up is done and the product is prepared for shipping to the customer.

5.3 Areas of Opportunity

5.3.1 Preproduction Process not Aligned

Preproduction processes comprise 4 of the required 5 week order throughput time (from order to ship). Many opportunities for improvement existed in this area including: reducing orders accumulated between process steps and improving the office layout to better support information sharing. Historically, frequent delays in the preproduction process occurred due to missing information or material and changes to orders were not well communicated through the chain; Generally, production was the last to know about changes to an order. In addition, there was no single person who was responsible for the order process; i.e., no ownership, or accountability.

5.3.2 Poor Workplace Housekeeping

Although the factory had implemented 5S in some areas, opportunities for improvement still existed. Throughout the factory and warehouse, excess inventory and tooling existed in the work areas. Parts and tools were not clearly labelled and were not routinely stored in the same location.

5.3.3 Work in Process Not Visually Controlled

Although the Zaragoza factory already improved many of the operational aspects of its factory, the amount of work in process was still not directly controlled in a visual way and high WIP levels had caused factory disturbances in some of the buffer areas. Variation in work content, disruptions in material flow and incomplete information were all factors complicating improvements to targeted WIP levels.

5.3.4 Unreliable Inventory Data

Much of the data in the system that records inventory levels could not be relied upon for accuracy. As a result many inefficient and time consuming backup processes (i.e., visual checks, floor worker requests, and spreadsheets) had been implemented to attempt to control current inventory levels and forecast future material needs. The reasons for inaccurate data stemmed from many sources, including errors related to material definition on the bill of materials, incorrect material usage on the shop floor and the fact that data errors were overly difficult to correct when discovered..

5.3.5 Lack of Understanding of Supplier Processes

Although lead times and order placement details are known, the high-level supplier processes are not fully understood. With supplier on time deliveries at nearly 60% it is important to get a better understanding of how suppliers process the material and to work to identify areas that could be improved with coordination from the ABB Zaragoza factory.

5.4 Executed Changes

As described, many of the improvements in Zaragoza needed to happen, not on the production floor, but with the processes that support production. Both the preproduction and supply chain integration processes have major issues that can be addressed with CP3 tools and methodology. The execution of the project plan is currently underway in Zaragoza and is expected to continue until the end of June, 2004.

5.4.1 Mapping the Value Stream

The factory processes in Zaragoza were documented using value stream mapping techniques. The current state value stream map was created by walking through the factory with a team to gather information. Using this data a rough map was created and reviewed by the team. The information was then documented in the value stream map and is shown in Figure 16.

Once the selection of the Zaragoza factory was confirmed, a team of people was assigned to the project including resources from the CRC, local factory personnel and the author of this thesis. The factory manager and the two local project leaders flew to Italy to visit the factory and perform basic lean training with the team that implemented the change in the Monselice factory. This knowledge exchange proved very valuable, as the team from Zaragoza was able to see the changes that had been made and could start to envision how these changes might affect their factory.

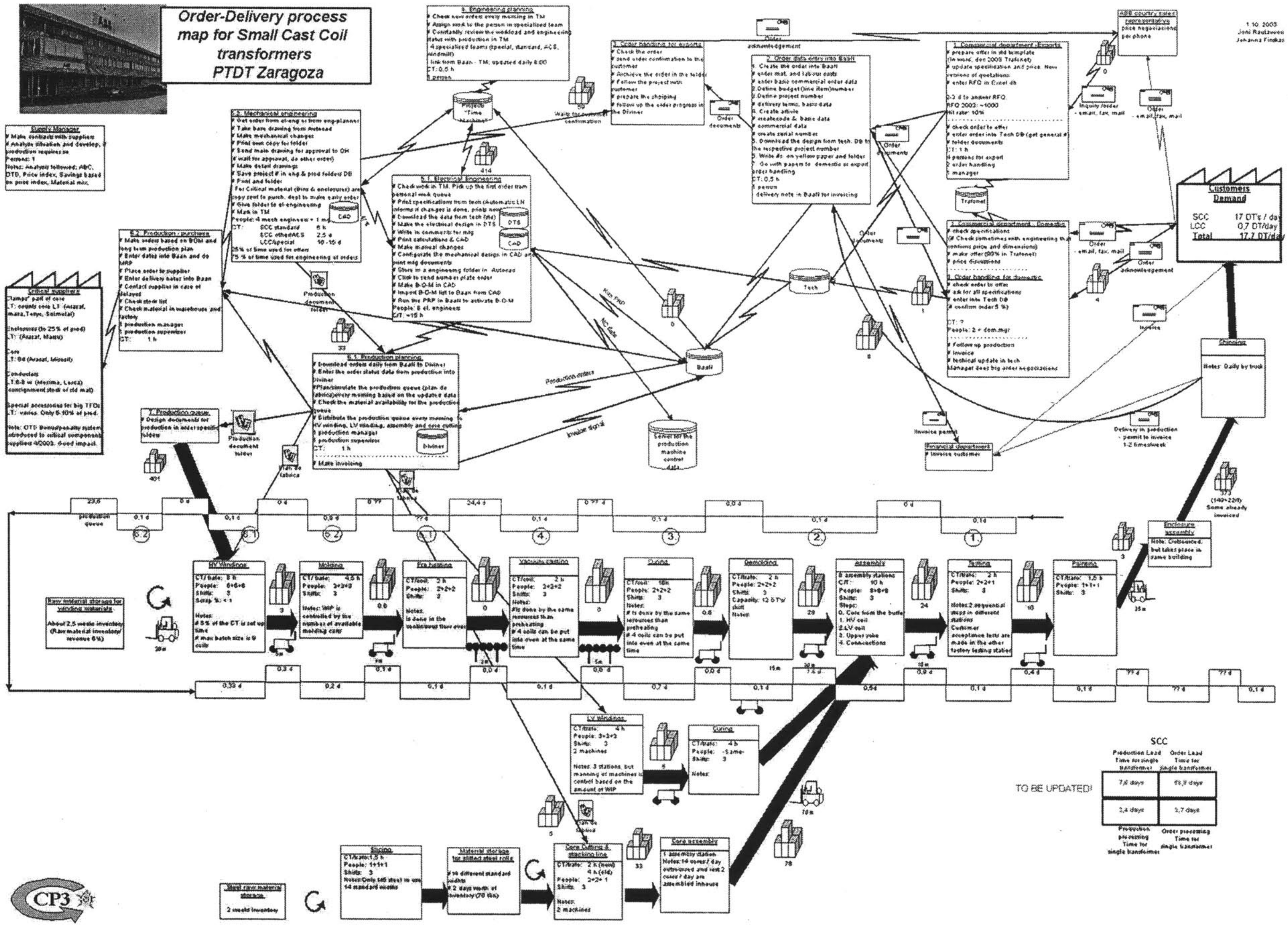


Figure 16: Zaragoza Current State Value Stream Map

During the visit to Monselice, sessions were held to review the current value stream map that had been created, brainstorm future improvement ideas and discuss a future state value stream map. An initial future state map based on group brainstorming was created by the CRC consultants in Finland and brought to Monselice for discussion. The result of this session is shown in the future state value stream map in Figure 18.

5.4.2 Creation of Key Performance Indicators

During the first two weeks of the planning phase, each of the individual "work package" groups held a kick-off meeting to discuss the basic scope of their tasks. As part of the start of the 5S work package, improvement teams were formed on the factory floor.

Each of the work package teams also discussed the KPIs that would be used to track the progress of their changes. A set of project KPIs was established with both short term and long term targets. Where applicable, existing KPIs were used, but additional KPIs such as throughput time, housekeeping index, and employee satisfaction were created. Targets for the KPIs were set for future dates. The KPI table created from Zaragoza is shown below:

KPI	% Improvement
Hours/unit	27%
Total Throughput Time	50%
Manufacturing TPT	30%
Inventory Total	29%
- WIP reduction	50%
- FG reduction (Cast coil)	13%
- FG reduction (Resales)	35%
- Raw material reduction	29%
OTD	8%
Suppliers OTD	23%

Figure 17: Zaragoza Key Performance Indicator Targets

Using historical data and projected KPI improvements, a benefits calculation was performed to calculate the future cash flow impact of implementing the planned changes.

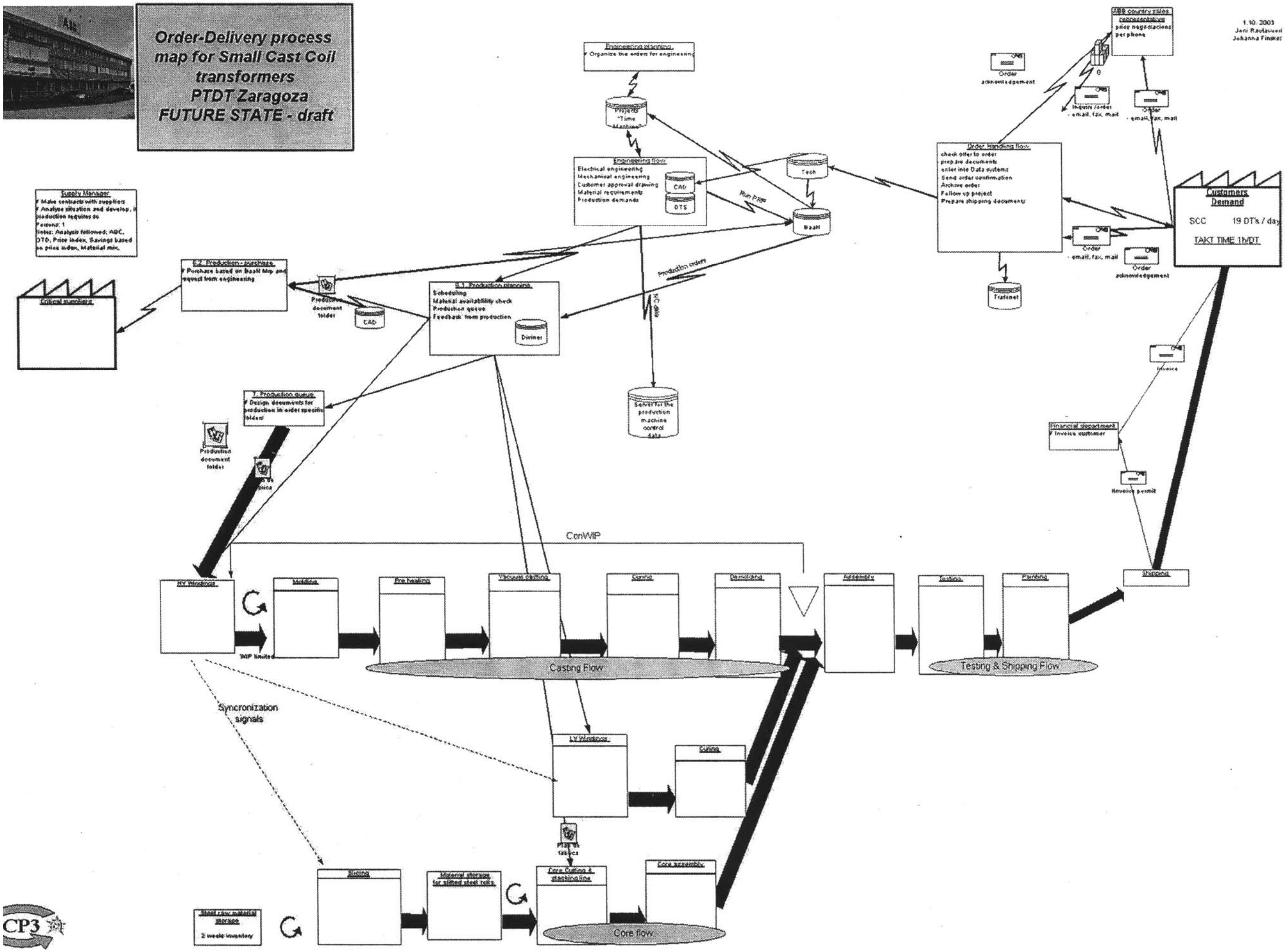


Figure 18: Zaragoza Future State Value Stream Map

5.4.3 Visualization of WIP Levels

In Zaragoza, the factory capacity constraint was closely analyzed using pull production methodology prior to the implementation of CP3. The production control system in place was performing well before the start of the project, but room for improvement existed. Instead of implementing a new control model, it was decided that a better solution would be to identify improvements to the current system. The focus of pull production control in Zaragoza is on determining the desired levels of WIP and introducing ways to control these levels both visually and using the current production control system.

The first step to accomplish this is to perform a detailed analysis of current factory processes. Using this information, a calculation of desired WIP levels can be performed. Details on the ConWIP level calculations are provided in Appendix A.

The next step in the implementation is to identify ways to control the WIP using the current production control system and visual controls. In order to modify the current control system only minor modifications are required. The biggest challenge of implementing this change is changing the mindset of the factory workers so that when WIP levels are exceed, production does not continue. The pull production team is working to identify ways to improve the visualization of production processes and is due to be implemented before the end of the Zaragoza CP3 project.

5.4.4 Creating Continuous Flow in Preproduction Processes

To determine how to improve preproduction the processes, value stream mapping techniques were performed to gain a better understanding of the process. The flow of information and orders was mapped to identify and eliminate waste. The order takt time was also determined so the rate at which orders should be processed to meet demand could be better understood and the process could be redesigned to match takt time with processing time.

With this basic understanding, work elements for each of the processes were determined and basic studies of the amount of time required to execute the tasks were performed. The number of resources, takt time, and processing times were all reviewed to decide where groups were overloaded and to identify ways to balance the work load.

The information from this analysis was used to create a preliminary new plan for preproduction processing, which was presented to the employees in preproduction areas. Additional brainstorming and discussions lead to revisions of the process to incorporate the inputs of all affected employees.

The information from the preproduction analysis was also used to define a new preproduction office layout. The new office layout is designed to improve communication between departments to ensure more efficient handling of orders.

5.4.5 Improving Continuous Flow in the Factory

The main focus on the implementation in Zaragoza has been creating continuous flow in preproduction processes. As this part of the implementation has been completed, focus has shifted to improving flow in the factory.

To approach the factory flow improvement project, a continuous flow study will be performed on the factory floor. The project has already started with the mapping of the value stream, calculation of the factory takt time, and identifying current work elements. The next major area of focus will be to perform process time studies and create detailed value stream maps of each area to identify and eliminate waste.

The factory layout in Zaragoza is designed for overall product flow, but some areas for improvement still exist. The process time studies should identify areas where raw material and information flows can be improved. It is hypothesized that some improvements will include: increasing the amount of material at point of use, improving the information flow for the start of jobs, and the implementation of standard worksheets to describe factory processes.

5.4.6 Deployment of 5S Practices

5S projects had been started in the Zaragoza factory a few months prior to the start of the CP3 implementation and were led by two employees of the quality department. Although significant improvements were made, many areas need further improvement.

The 5S implementation began with basic training of the factory employees. Several sessions were held with each shift to explain the importance of 5S and the process that would be used to implement it in the Zaragoza factory. In order for employees to get a first hand view of how 5S could be implemented a benchmarking trip was made to a local automotive parts manufacturer. The trip provided real life examples and employees from that factory shared their experiences regarding the challenges and benefits of implementing 5S.

Once the training and benchmarking was complete, employees were ready to start the 5S implementation. The molding area was chosen for a pilot implementation to demonstrate the value of 5S. Because molding area is a highly visible location in the factory, all employees are able witness the results.

The full implementation of 5S has since been initiated throughout the factory. Each work area has begun to remove unneeded material, a dedicated holding area for "red tag" or unnecessary material has been established, and the progress is being closely monitored. Although the implementation has been slower than planned due to a high factory load, it is expected that progress will continue over the next few months.

5.4.7 Integration of the Supply Chain

The implementation of supply chain improvements in Zaragoza began with a basic supply chain assessment. Each of the purchasing agents was interviewed to get an understanding of the current processes used to coordinate the purchase and shipment of material.

Data was extracted from the BAAN ERP system to perform an ABC analysis. This analysis showed that the distribution of parts followed a typical ABC analysis pattern. A detailed explanation of how the ABC analysis was performed is included in Appendix B.

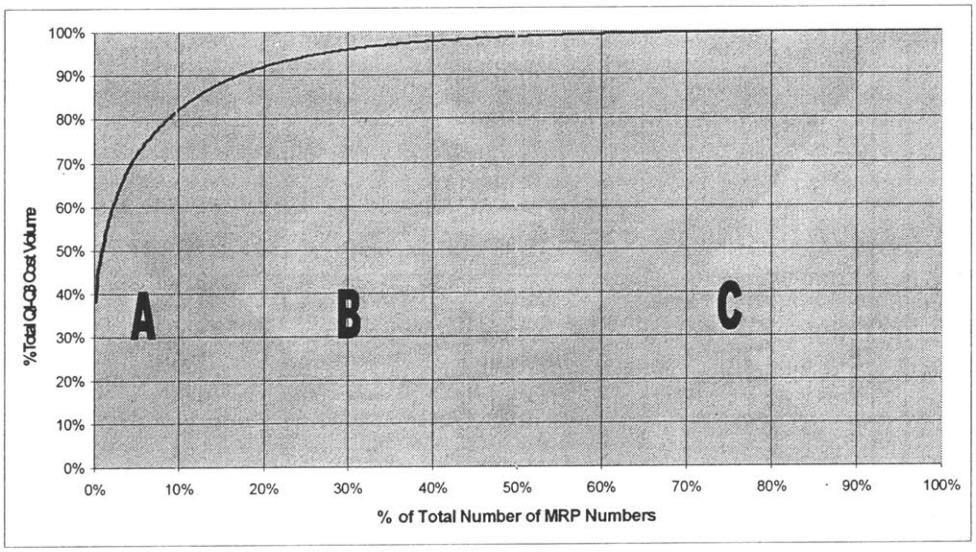


Figure 19: Zaragoza ABC Material Analysis

A review of purchasing methods was made using a Kraljic[26] matrix to analyze the factory purchasing methods. The matrix classifies components on two dimensions; impact to profit and supply risk. The results from the ABC analysis were used to determine the impact to profit and to determine overall supply risk, each of the components was analyzed by considering factors such as: how many suppliers there are? who could offer that part? and whether the part was standard? or custom?. The results were plotted on a 2x2 matrix as shown in Figure 20. Each component is now identified as either leverage, bottleneck, non-critical or strategic. The results were analyzed to determine where future changes should be focused.

The final part of the supply chain analysis was to review current inventory levels. A detailed explanation of the process used to review inventory levels is included in Appendix C. Overall inventory levels were reviewed and areas with excessive inventory were targeted for improvement.

[26] See Appendix C for additional details on the creation of a Kraljic Matrix

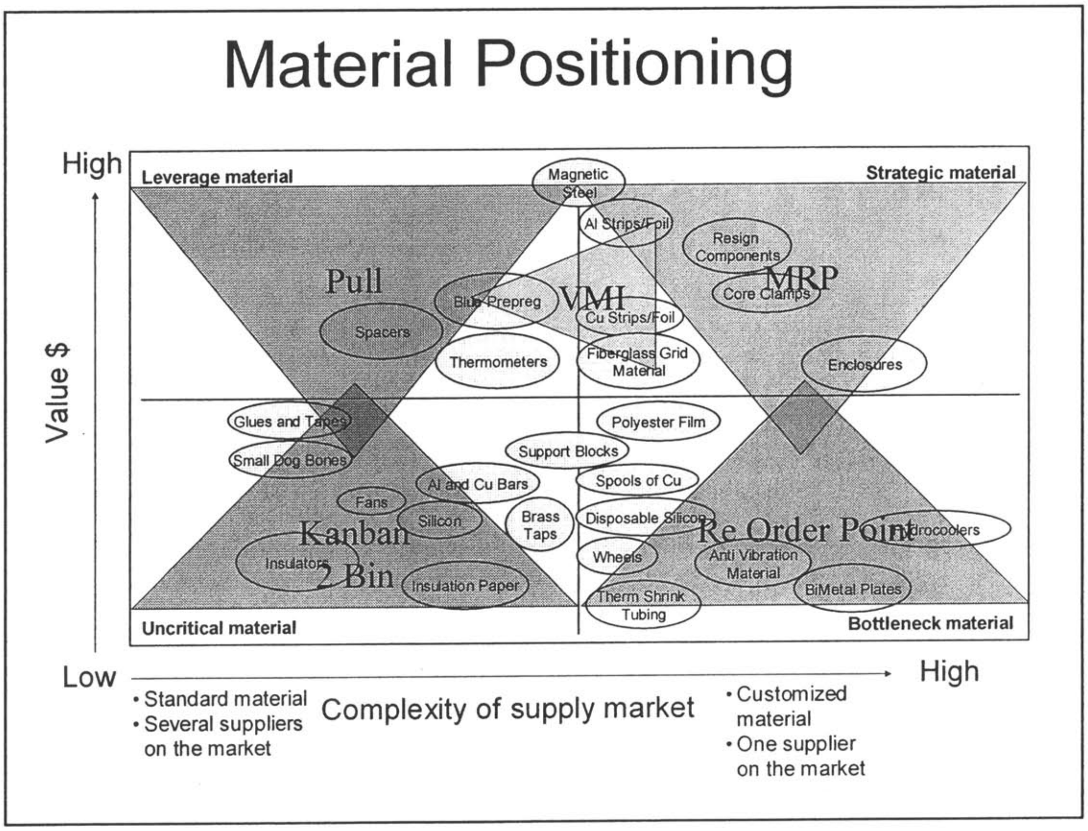


Figure 20: Zaragoza Material Positioning Matrix

Using the results of the ABC analysis, kraljic matrix and inventory level analysis, different commodities were reviewed for implementation of a kanban pilot. The supply chain team brainstormed the different options and weighted each based on the visibility of the pilot and the potential impact. Aluminum and Copper Bar stock were selected. In order to determine the proper Kanban levels the process described in Appendix D was used. The kanban pilot is currently in process and is expected to reduce inventory by 56%.

5.5 Sustaining Changes Made

The sustain phase of the CP3 implementation is scheduled to begin in June, 2004. This stage will occur after the completion of most of the major project implementations and mark the start of the continuous improvement phase of CP3.

Chapter 6. The Value of a Common Approach to Lean

The benefits of using lean manufacturing have been repeatedly proven at companies around the world. What lean is today is based on how operations were defined by Toyota more than 50 years ago. Over the years, individual companies have taken the Toyota Production System approach and customized it for application in their working environments. The benefits and drawbacks of standardizing the approach on a corporate wide basis is not as clear as the benefit of applying the general principles at a local level. Using the Monselice and Zaragoza case studies, this chapter will explore both the benefits and challenges of creating and applying a standard corporate wide approach to lean.

6.1 Challenges of a Standard Approach to Lean

Multiple challenges exist when defining and implementing a standard approach to lean. Some of the challenges experienced during the creation and implementation of CP3 include selecting the appropriate level of detail, lack of customization at the local level, and language barriers leading to a top down approach. Each of these challenges can be overcome, but need to be kept in mind when a standard approach to lean is developed.

6.1.1 Selecting the Appropriate Level of Detail

One of the major challenges of creating a standard approach to lean is determining the proper level of detail. The framework used should be simple and described in a clear and concise way. When implementations are described in lengthy and complex ways few employees will take the time to read the details, this is especially true in countries where English is not the native language. Conversely, the operating system for lean should provide the framework and tools at a detailed enough level that employees will approach the same problem in a similar manner. Finding the balance between simplicity and detail can prove to be a difficult task.

6.1.2 Lack of Customization at the Local Level

As one employee in Zaragoza noted, "You must come first to learn then to teach. You must work to transmit this with your attitude." Using a standard approach can lend itself to the feeling that a location's individual needs are not being specifically addressed. The tools and solutions need to be "localized" for different areas or factories to account for local culture and maturity. The standard approach to lean should be used as a standard way to approach the identified problems, not for a standard solution.

6.1.3 Top Down Implementation Model

The vision for lean implementations must be created and supported by senior management, but in order for the implemented changes to stick, the solutions to the problems need to be identified by employees on the factory floor. In the case of ABB, the CP3 implementations are centrally controlled by the Corporate Research Center.

Because the ABB factories are located in countries around the world, often the only common language is English. Although English is the official language of ABB, it is normally only spoken by the factory management, not those on the factory floor. In these cases, the implementation of lean principles may be very top down. In Monselice, this was mitigated by bringing in local external consultants to run training sessions in Italian. In Zaragoza, the project leader selected was fluent in Spanish. As the implementations move forward, careful consideration will need to be made to ensure that that the language barriers with those who work on the factory floor is overcome in order to create change that will last.

6.1.4 Centrally Controlled and Staffed Implementation Model

A problem with a centrally controlled and staffed implementation model is that it limits the speed at which lean can be spread across the country. At ABB, the current limit for implementations is approximately 8 factories per year, yet ABB's PTDT Business Area has more than 30 factories around the world. ABB is currently working to identify new ways to increase the implementation process capability by creating alternate ways to spread the implementation of lean, such as using resources from previous factories and bringing additional resources into the Corporate Research Center.

6.2 Value of a Standard Approach to Lean

The implementations at Monselice and Zaragoza provide an opportunity to see how valuable a standard approach to lean can be, despite the challenges noted above. The benefits of this type of lean operating system include creation of a common culture, common language, alignment of upper management, increase in the velocity of implementation, and improvement in implementation results.

6.2.1 Creation of a Corporate Culture

The use of a standard approach is valuable in the creation of a corporate culture. Standard implementation processes and practices create a common language focused around operational improvement and a culture with predictable and stable behaviors. A significant benefit of a common approach is that employees across the enterprise all respond to problems in the same way using similar procedures. In the case of ABB, as the culture of CP3 develops it will become more "ingrained" in the behavior of employees and become a key component of the corporate culture.

6.2.2 Alignment of Upper Management

In addition to unifying the corporation around lean principles, a common approach will also work to align and focus the management team on the proper aspects of a single corporate process. In the case on ABB, the areas of focus are continuous flow, pull production control and supply chain integration. Having this division wide focus across globally dispersed sites will help align management priorities and facilitate the implementation. Additionally, the creation of common key performance indicators for factories sets up a system that allows consistent management monitoring across all factories and benchmarking within the enterprise.

6.2.3 Increase in the Velocity of Implementation

By defining common tools and methodologies used for operational improvement projects, less time is spent developing the processes allowing more time for implementation, training, etc. Additionally, each new implementation project will generate lessons learned which will aid future implementations. A key component of a common approach is the framework and tools used for implementation. In many cases, the need for improvement is recognized, but the steps and tools required are unknown. Having a lean framework provides the guidance and a standard set of tools to conduct a successful implementation. In most cases, the necessary tools will be selected based on greatest benefit and will undergo minor changes to fit the locality.

Having a standard approach defined by ABB allows for a common training program for the tools and processes, eliminating the need for training to be developed at each site. In addition, the training materials can be expanded to include the ABB success stories to illustrate results achieved using the common tools in scenarios similar to the location conducting the training.

6.2.4 Improvement in Results

It has been shown that implementing lean principles will improve the results of a factory. Based on experiences at both Monselice and Zaragoza, it is evident that this is also true for having a standard approach to lean. Having a standard operating system allows success stories (and failures) to be shared. Many of the factories within ABB have the same areas of opportunity, such as long lead times, high levels of WIP, and preproduction process that are not well integrated. Because these factories produce the similar products and face the same issues, benchmarking and sharing experiences will increase the results of implementations. Factories can learn from each other's failures and do not have to incur the costs of these mistakes.

Another reason the results are increased for the company is that it enables lean manufacturing to be implemented in factories without the resources or expertise to define how the lean implementations should be approached. ABB is composed of many small factories with less than 200 employees. Often these factories do not have people who can focus full time on lean improvement projects. Having a structured approach with milestones for completion along with support of the implementation provides the required assistance to ensure that lean can be effectively implemented in these smaller factories. Once the implementation is completed, local experts will exist at each of the individual factories. These experts can continue to implement lean changes and improve factory operations.

A harder to quantify reason is improved customer and supplier relations. Customers who have products produced in multiple factories see consistent lean principles applied throughout ABB and will see improved products as a result. Suppliers who supply parts to multiple ABB factories will have consolidated processes to deal with making it easier to integrate ABB operating procedures into their own.

6.3 Summary

"When the rate of change outside exceeds the rate of change inside, the end is in sight"

- Jack Welsh, CEO of General Electric

ABB is working to leverage both its size and its experience in order to improve and remain competitive in the market. ABB's history of autonomous factories that compete against each other makes this difficult. CP3 has created a division wide process which has found a way to leverage experiences and spread operational excellence. The benefits of CP3 for ABB are clear. Now that a common approach to lean has been proven in one division, opportunities exist through quickly spreading lean across the company. Companies, such as GE have spread operational excellence programs across the entire company, every division, location, and function, within 4 years. In order to remain competitive, ABB must strive to do the same.

For other global corporations similar to ABB, it is evident that there are clear advantages to creating a standard operating system for implementing lean manufacturing. Learning the tools of lean is not enough. These tools must be adapted in a way that makes sense for a company and ingrained into the corporate culture. Defining a lean operating system provides value to the customer, the corporation, employees, and suppliers. Creating and implementing a standard approach allows the thrust towards corporate wide lean to be promoted and ensures that companies can remain competitive.

As with all lean projects, companies who have already developed lean operating systems must continue to review and improve them. As Womak explains, "it is... important to continuously conduct experiments – that's what kaizen is – to search for better operating methods and to incorporate new methods in the standard system once they are proved superior".[27] Companies need to benchmark each other and look carefully at themselves in order to determine effective ways to evolve these practices over time. As standard approaches to lean are expanded across the enterprise to suppliers and customers, a slow convergence across industries on standard lean operating systems will occur. The companies with the best operating system in their industry will likely create the industry standard.

[27] Jim Womack, "Dueling Sensei and the Need for a Standard Operating System," e-mail to the author, 11 Sept. 2003.

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Appendix A: Performing ConWIP Calculations

Chapter 4 describes the how initial ConWIP levels in Monselice were set to higher than optimum with the goal of lowering them over time. Eventually the ConWIP levels in Monselice will be fine-tuned. In order to determine a goal for long-term improvement the model suggested in the book Factory Physics was used.[28]

1. Determine Average Natural Process Time, t_o, and Number of Workstations, n.

   Natural process time, t_o, is the amount of time it takes to process a unit at a workstation including variability from "natural" sources such as differences in operators, material, or machines. The calculations assume that the machines are reliable and most of the variance in the system arises from natural sources. The average natural process time, t_o, is the sum of the individual processing times historically observed, $t_o(j)$, at a given workstation divided by the number of samples taken, N.

   The number of workstations for a process, n, is usually a known quantity and is determined by reviewing factory processes to determine how many parallel lines or machines there are for a given process.

2. Determine Effective Process Time, t_e and Effective Station Rate, r_e.

   ConWIP calculations are performed using a mean value analysis MVA, but this type of analysis is not valid for a multimachine case.[29] Instead, the parallel machines are approximated using effective process time, t_e, which estimates a multimachine case using a single fast machine. To calculate the effective process time the following formula is used:

$$t_e = \frac{t_o}{n}$$

[28] Factory Physics. Chicago: Harvey, Inc., 2000.
[29] Ibid, 330.

The effective station rate, r_e, is the inverse of the effective process time and is calculated as follows:

$$r_e = \frac{n}{t_o}$$

3. Coefficient of Variation of Process Time

Previous process times are analyzed to determine the standard deviation of process time. The formula to calculate the standard deviation is:

$$\sigma_e^2 = \frac{\sum (t_o(j) - t_o)^2}{N}$$

Using the standard deviation the Coefficient of Variance can then be determined using the following formula:

$$c_e^2 = \frac{\sigma_e^2}{t_o^2}$$

5. Determine Bottleneck Rate of the Line, r_b.

The Bottleneck Rate of the Line is the rate of the workstation having the lowest capacity of all the processes on the line. The Bottleneck Rate is calculated by taking the minimum effective station rate $r_b = \min(r_e(j))$

6. Determine Raw Process Time, T_o

The raw process time is the sum of the natural process times. It is the average time it takes a product to be processed through a line with no WIP. It is computed using the following formula: $T_o = \sum t_o(j)$

7. Critical WIP Level, W_o

The critical WIP level is the WIP level that achieves the highest throughput with the minimum cycle time when no variability exists. The formula for calculating Critical WIP level is: $W_o = r_b T_o$

8. Start with the case of WIPj(0) = 0 and TH(0) = 0

The model is based on the Mean Value Analysis technique explained in Factory Physics. WIP levels for a given WIP level, w, are determined based on the WIP level w-1 using an iterative process. To begin the analysis the base condition of throughput at time zero, TH, and WIP level, WIP_j, are set to zero at time zero.

$$TH(0) = 0$$
$$WIP_j(0) = 0$$

9. Determine cycle time at each station, $CT_j(w)$

Cycle time at each station j with WIP level w is determined using the following formula:

$$CT_j(w) = \frac{t_e^{\,2}(j)}{2}\left[c_e^{\,2}(j) - 1\right]TH(w-1) + \left[WIP_j(w-1) + 1\right]t_e(j)$$

10. Calculate the cycle time of the line, $CT(w)$

The cycle time of the line with WIP level w is calculated by summing the cycle time of each of the individual stations:

$$CT(w) = \sum_{j=1}^{n} CT_j(w)$$

11. Determine Throughput of line $TH(w)$

The throughput of the line is then calculated using a Little's Law:

$$TH(w) = \frac{w}{CT(w)}$$

12. Calculate the WIP level at station j with WIP level w $WIP_j(w)$

The WIP at each of the individual work stations can be calculated using another form of Little's Law:

$$WIP_j(w) = TH(w)CT_j(w)$$

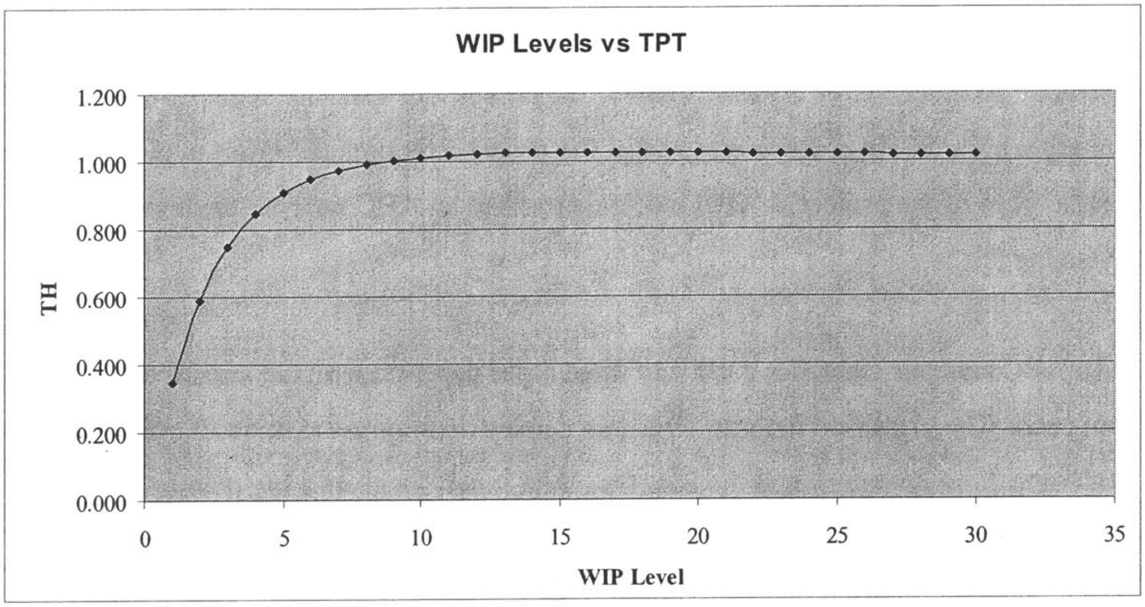
Example of Results:

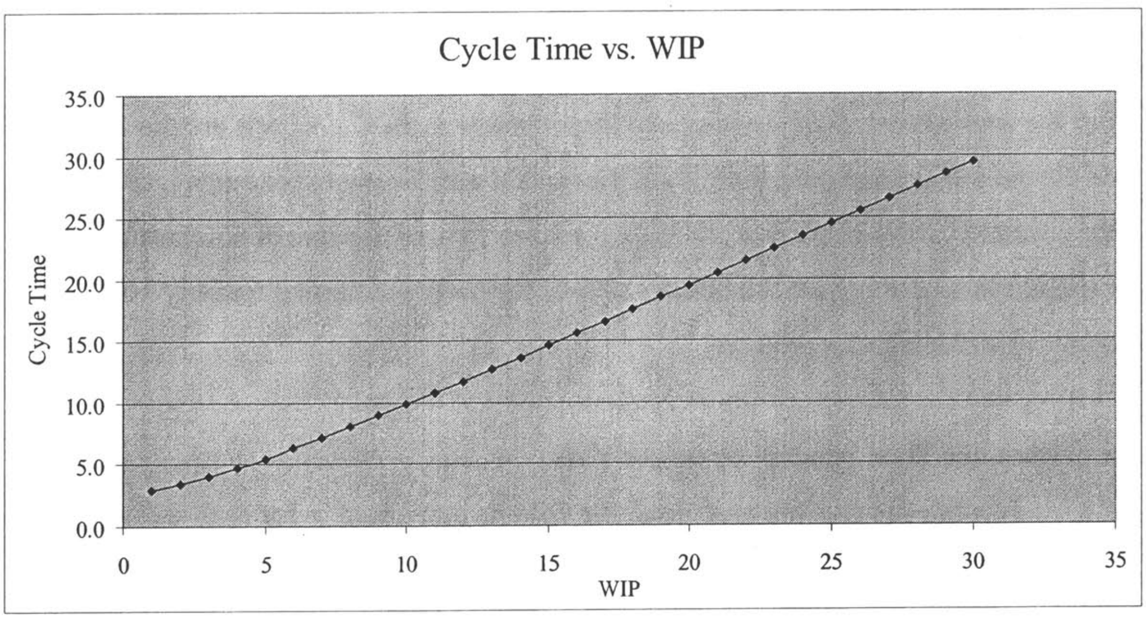
Variable	Name	Units	Windings*	Supermkt	Assy	Drying
n	Number of Work Stations	workstations	12	10	6	3
t_o	Natural Process Time	days/unit	9	3	5	3
Ce	CV of effective process time		0.5	0.5	0.5	0.5
r_e	Effective Station Rate	units/day	1.33	3.33	1.20	1.00
t_e	Effective Process Time	days/unit	0.75	0.30	0.83	1.00

r_b	Bottleneck Rate of the Line	units/day	1.00
T_o	Raw Process Time	days/unit	20.00
W_o	Critical WIP Level	units	20.00

* = includes clamping and drying

WIP Level	TH	CT	$CT_1(w)$	$WIP_1(w)$	$CT_2(w)$	$WIP_2(w)$	$CT_3(w)$	$WIP_3(w)$	$CT_4(w)$	$WIP_4(w)$
1	0.347	2.9	0.750	0.260	0.300	0.104	0.833	0.289	1.000	0.347
2	0.590	3.4	0.872	0.514	0.320	0.188	0.984	0.580	1.217	0.717
3	0.749	4.0	1.011	0.757	0.337	0.252	1.163	0.871	1.496	1.120
4	0.849	4.7	1.160	0.984	0.350	0.297	1.364	1.158	1.839	1.561
5	0.911	5.5	1.309	1.192	0.361	0.328	1.577	1.436	2.243	2.043
6	0.950	6.3	1.452	1.380	0.368	0.349	1.793	1.704	2.701	2.567
7	0.976	7.2	1.585	1.546	0.373	0.364	2.006	1.957	3.210	3.133
8	0.993	8.1	1.704	1.692	0.376	0.374	2.210	2.195	3.767	3.740
9	1.005	9.0	1.809	1.818	0.379	0.380	2.404	2.415	4.368	4.388
10	1.013	9.9	1.901	1.925	0.380	0.385	2.584	2.616	5.011	5.074
11	1.018	10.8	1.980	2.016	0.381	0.388	2.750	2.799	5.694	5.797
12	1.022	11.7	2.047	2.092	0.382	0.390	2.901	2.964	6.415	6.554
13	1.024	12.7	2.103	2.154	0.383	0.392	3.037	3.110	7.171	7.344
14	1.026	13.7	2.149	2.204	0.383	0.393	3.159	3.239	7.960	8.163
15	1.026	14.6	2.187	2.245	0.383	0.393	3.266	3.352	8.779	9.010
16	1.027	15.6	2.217	2.276	0.383	0.394	3.359	3.449	9.625	9.882
17	1.027	16.6	2.240	2.300	0.383	0.394	3.440	3.531	10.497	10.775
18	1.026	17.5	2.258	2.318	0.383	0.393	3.509	3.601	11.390	11.688
19	1.026	18.5	2.272	2.330	0.383	0.393	3.567	3.658	12.304	12.619
20	1.025	19.5	2.281	2.338	0.383	0.393	3.615	3.705	13.234	13.564
21	1.024	20.5	2.287	2.343	0.383	0.393	3.654	3.742	14.180	14.523
22	1.023	21.5	2.291	2.344	0.383	0.392	3.685	3.771	15.139	15.492
23	1.023	22.5	2.292	2.344	0.383	0.392	3.709	3.793	16.109	16.471
24	1.022	23.5	2.292	2.342	0.383	0.391	3.728	3.809	17.088	17.458
25	1.021	24.5	2.291	2.339	0.383	0.391	3.741	3.819	18.075	18.451
26	1.020	25.5	2.289	2.334	0.383	0.390	3.750	3.825	19.069	19.450
27	1.019	26.5	2.286	2.330	0.383	0.390	3.755	3.827	20.068	20.453
28	1.018	27.5	2.282	2.324	0.383	0.390	3.757	3.827	21.071	21.459
29	1.018	28.5	2.278	2.319	0.383	0.389	3.757	3.824	22.077	22.468
30	1.017	29.5	2.274	2.313	0.382	0.389	3.755	3.818	23.087	23.480


WIP Levels vs TPT
1.200
1.000
0.800
0.600
0.400
0.200
0.000
TH
0
5
10
15
20
25
30
35
WIP Level


Cycle Time vs. WIP
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Cycle Time
0
5
10
15
20
25
30
35
WIP

Appendix B: Performing an ABC Analysis

Studies of inventories across a wide range of industries have shown a statistical regularity in usage rates of different items. Typically, 20% of the SKUs in an inventory account for 80% of the stock value. The majority of the purchasing costs are spent on only a small number of parts. In order to ensure that the proper attention and effort is placed on the right types of the project at ABB in Zaragoza used an ABC analysis as described in Chapter 5.

An ABC analysis classifies parts into three types depending on the annual amount spent on each. The classification into three types helps determine the tradeoff between the cost of controlling inventory and the benefits. ABC analysis gives a big picture idea of the inventory situation in simple, visual terms. To perform the ABC analysis, the process similar to that described in "Inventory Management and Production Planning and Scheduling"[30] was used.

For the analysis items are divided into three groups A, B, C. A Parts are the first 5-10% of the parts which account for 80% of the annual purchasing expenditures. B Parts are the second 10-15% of parts accounting for 10 to 15% of the annual purchasing expenditures. C Parts are the bottom 80% of the parts accounting for only 10% of the annual purchasing expenditures.

1. Determine Total Amount Spent per Year

    Identify the cost per unit c and the volume purchased v for each individual Stock Keeping Unit (SKU). Next, determine the total amount spent TA per year by multiplying cost per unit by volume purchased.

    $$TA = c * v$$

    Rank the values of total amount spent per year in descending order, beginning with the largest value.

[30] Rein Peterson, David F. Pyke, and Edward A. Silver, Inventory Management and Production Planning and Scheduling (Hoboken: John Wiley and Sons, 1998).

2. Cumulative Percentage of Total Parts

   Determine the total number of SKUs in the system and determine what percentage each SKU is out of the total number of SKUs. Create a cumulative sum of the percentages for each SKU.

3. Cumulative percentage of Total Amount Spent

   Determine the total amount spent for each individual SKU and divide by the total amount spent on all SKUs. Create a cumulative sum of the percentage of total amount spent for each SKU.

4. Plot the graph and determine A, B, C levels

   Plot a graph of cumulative percentage of total amount spent and cumulative percentage of total SKUs. Use this graph and the ABC guidelines to determine how to categorize parts into A, B, or C.

5. Use results to determine part control.

   Based on the ABC classification, part control should be reviewed. In general, the following guidelines should be applied:

   - A items represent a small number of items which represent a high value. These items should be closely controlled by using careful physical control, frequent audits, and small orders.
   - B Items are parts that should be controlled using moderate inventory policies such as computers and EOQ.
   - C Items are low value so they should be controlled using simple inventory policies such as control rules. Orders for these items should be large and placed infrequently.

MRP #	Amount Purchased	Units	Price/Uni	Total	Cum Total	$ %	PN %
60005000	4,278,200.00	kg	1.20	5,122,829.40	5,122,829	35%	0%
34400003	32,586.00	m2	10.71	348,996.06	5,471,825	37%	0%
45035030	116,300.00	kg	2.69	313,395.40	5,785,221	40%	0%
42095070	83,783.00	kg	2.38	199,739.97	5,984,961	41%	0%
34200056	71,907.00	kg	2.45	176,172.15	6,161,133	42%	0%
34117101	79,521.00	m2	2.08	165,403.68	6,326,537	43%	0%
34200044	59,000.00	kg	2.63	155,170.00	6,481,707	44%	0%
34200057	56,940.00	kg	2.70	153,738.00	6,635,445	45%	0%
45060050	55,486.00	kg	2.54	141,005.52	6,776,450	46%	0%
44050070	49,784.0	kg	2.79	139,008.69	6,915,459	47%	0%
45050050	52,805.0	kg	2.48	130,838.49	7,046,297	48%	0%
34200042	38,000.0	kg	3.27	124,260.00	7,170,557	49%	0%
45040050	44,410.0	kg	2.66	118,332.99	7,288,890	50%	0%
42135230	47,476.0	kg	2.33	110,756.02	7,399,646	51%	1%
44060050	38,078.0	kg	2.86	109,056.20	7,508,703	51%	1%
67200015	850.0	und	126.92	107,880.85	7,616,583	52%	1%
42115180	43,009.0	kg	2.28	98,244.87	7,714,828	53%	1%
42095125	37,870.0	kg	2.27	86,118.07	7,800,946	53%	1%
45040055	32,200.0	kg	2.67	85,817.25	7,886,764	54%	1%
41068110	31,478.0	kg	2.58	81,213.24	7,967,977	54%	1%
45040030	30,226.0	kg	2.68	80,958.63	8,048,935	55%	1%
29501015	86,400.0	und	0.89	76,896.00	8,125,831	56%	1%
45030030	28,136.0	kg	2.70	75,952.38	8,201,784	56%	1%
42120200	31,990.0	kg	2.33	74,613.20	8,276,397	57%	1%
42135150	30,001.0	kg	2.43	73,022.43	8,349,419	57%	1%
41095170	25,098.0	kg	2.88	72,390.42	8,421,810	58%	1%
90100513	9,600.0	pza	7.51	72,124.81	8,493,935	58%	1%
42115130	29,907.0	kg	2.37	70,811.13	8,564,746	59%	1%
41095125	24,598.0	kg	2.87	70,651.42	8,635,397	59%	1%
34400004	10,835.0	m2	6.49	70,329.99	8,705,727	60%	1%
45080100	25,791.0	kg	2.56	66,129.52	8,771,857	60%	1%
42095100	27,318.0	kg	2.38	65,021.32	8,836,878	60%	1%
34117121	29,252.4	m2	2.08	60,844.99	8,897,723	61%	1%
25182014	41,652.0	m	1.44	60,079.64	8,957,803	61%	1%
27000041	18,156.0	kg	3.27	59,431.71	9,017,234	62%	1%
67400005	333.0	und	176.91	58,910.36	9,076,145	62%	1%
48612012	19,057.2	kg	2.82	53,699.51	9,129,844	62%	1%
67400004	342.0	und	155.24	53,092.42	9,182,937	63%	1%
35A00001	22,840.0	und	2.29	52,303.60	9,235,240	63%	1%
45050030	19,578.0	kg	2.65	51,882.31	9,287,123	63%	1%

Appendix C: Creating a Kraljic Matrix

The Kraljic Matrix is a method used to analyze factories purchasing portfolio methods. The matrix classifies products based on two dimensions: impact to profit and supply risk. The result is a 2x2 matrix dividing products into four classifications: bottleneck, non-critical, leverage and strategic items. Using a Kraljic Matrix allows for categorization of parts into and leads to identification of optimal purchasing plans. In order to create a Krajlix Matrix in Zaragoza the following process was used:

1. Calculate impact to profit

   First the impact to profit was determined by grouping parts into commodities and ranking each commodity by the total amount spent per year. Use this to help gauge the impact to profit

2. Determine supply risk

   Next the supply risk was determined. Look at things like whether these are commodities, how many suppliers are available, how much supplier power they have

3. Construct a Kraljic Matrix.

   Create a 2x2 matrix, plotting supply risk on the x axis and profit impact on the y axis. Identify each quadrant of the matrix as either leverage, bottleneck, non-critical, or strategic. Place each of the major commodities analyzed in the proper location.

4. Analysis components for purchasing improvements

   Leverage items have a low supply risk, meaning that the company has a high purchasing power. Purchasing methods should work to exploit the purchasing power and should work to implement pull production techniques.

Bottleneck items are high risk and low value. They should be handled with caution by keeping safety stock and implementing re-order point systems. Because these are low value and high risk the long term, goal for bottleneck items is to find other alternatives. Over the long term, specifications should be broadened to create a lower dependence on the supplier.

Non-critical items have both a low impact to profit and a low supply risk. Efficient processing methods such as kanban should be implemented.

Strategic are have both a high impact to profit and are high risk. Short term, these products should be managed using systems such as MRP. Over the long term, companies should look to diversify and balance supplier contracts in order to reduce supplier risk.

Appendix D: Determining Kanban Levels

Kanban is a signal device used to provide the authorization for production in a pull system. A kanban system is used to manage the flow of material so that products are produced only when the customer demands a product. This system provides a limit on inventory in the pipeline and is an ideal method for exposing problems and opportunities for change.

In the case of Zaragoza the kanban cards were used as signals to trigger purchasing to order additional parts from the supplier. The process used to perform the kanban calculations for the Zaragoza implementation is based on that in Inventory Management and Production Planning and Scheduling[31] and is described below:

1. Determine the usage rate D_i and Lead Time LT_i for each part i

    To determine the average demand the weekly demand data was analyzed for the previous 10 months. The weeks during the plant shut down were removed from the data set and an average was taken.

2. Determine the Demand During Lead Time, $\mathrm{DDLT_i}$

    The demand during lead time is the number of units demanded during the product order lead time. The formulae for Demand During Lead Time is as follows:

$$DDLT_i = D_i * LT_i$$

3. Determine Safety Stock Levels, $\mathrm{SS_i}$

Determine the number of parts desired to be kept as a buffer in case of late delivery or changes in demand. A conservative number to start with is 25% of the expected Demand During Lead Time (DDLT)[32].

$$\mathrm{SS_i} = .25 * \mathrm{DDLT_i}$$

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[31] Rein Peterson, David F. Pyke, and Edward A. Silver, Inventory Management and Production Planning and Scheduling (Hoboken: John Wiley and Sons, 1998).
[32] Ibid, 640.

4. Determine Number of parts per Kanban Bin (N)

   Think about the parts and look at the average usage. Determine a logical number of parts to include per bin based on factors such as current shipment size or storage container requirements.

5. Determine Number of Kanbans required (K)

   The last step in the Kanban Calculations is to determine how many Kanbans are required. To calculate this number you need all the numbers described above. Place the numbers in the formula below. This number should be rounded up to the next integer.

$$K_i = \frac{DDLT_i + SS}{N}$$

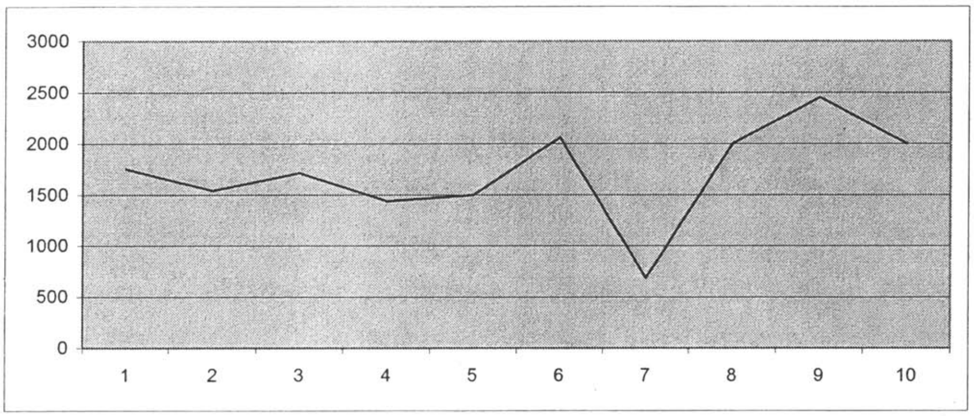
Kanban Product Data Sheet

Product Name:	PLET COBRE SEMIDUF	English Name:	Cu Bar
MRP Number:	48012010	ABC Designation:	A

Product Inventory Data:

Current Inventory:	1,794	units
	4,247	Euros

Consumption Data:



Appx Daily Demand	86	units
Order Frequency	1	day
Lead Time	25	days
Safety Stock	0.25	percent
Container Quantity	1000	units

Kanban Data

# of Kanban Cards	2.68	cards
DDLT	2144	units
SS	536	units
Avg Inventory	1608	units