Improved Integration of Information in Discrete Part Manufacturing Environments

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ABSTRACT

The flow and coordination of information across an enterprise is handled through complex networks of manual and automated processes. Forty years ago, the proliferation of computers spawned a revolution in automating many functional silos within a business via Material Requirements Planning applications. These systems evolved over time into Enterprise Resource Planning (ERP) solutions as more functionalities were included in the scope of their planning modules.

Only four years ago, the availability of high bandwidth Internet access at the corporate level also started revolutions beyond company walls, with Supply Chain Management and Customer Relationship Management applications. Companies have recently invested heavily in these Business-to-Business (B2B) and Business-to-Customer (B2C) solutions. However, electronic commerce, or "e-Commerce", has thus far been unable to achieve its "Shop Floor to Top Floor", "Sensor to Boardroom", or "Factory Floor to Executive Door" transparency of data as it was intended to do. The reason for this failure is that these applications typically lack direct links to the real-time status information from manufacturing operations.

This thesis attempts to bridge the gap between the enterprise wide applications and the vast amount of data trapped in the controls and machinery on the manufacturing floor. The vision to integrate these pieces is referred to as electronic manufacturing, or more commonly "e-Manufacturing". This newly emerging e-Manufacturing market is expected to offer rapid growth for companies who can move fast enough to capture a sizeable share.

While ERP vendors appear best positioned to push from the "top-down" into this space, this thesis demonstrates that the control vendors with a "bottom-up" strategy may prove to be more successful. The developments in this thesis are built upon ABB's Industrial^{IT} technology. Given Industrial^{IT}'s ability to quickly integrate to a variety of data sources in real-time, e-Manufacturing related feasibility studies were conducted in four of ABB's facilities. The thesis also suggests strategies for implementing these kinds of solutions successfully.

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1.0 INTRODUCTION

1.1 e-Manufacturing Bridges Enterprise Planning, Supply Chain and Operations

This thesis examines the complicated network of information flow that is required to run a business. Although several parts of the network have been automated, one critical link that is often missing is the connection between the *Enterprise Resource Planning* (ERP) software in the front of the organization, the newer Collaboration tools that integrate the supply chain, and the production floor operations in the back end. This integration is becoming increasingly important with the globalization of manufacturing operations [12]. In the semi-conductor industry, for example, wafers are produced in the United States but are assembled in Central America or Southeast Asia. Both cultural differences and the large physical separation require more advanced means of communication between functional areas.

The control vendors that provide mission critical data on the shop floor are starting to develop linkages here in an attempt to integrate "islands of automation". The ERP vendors are pushing down into this space with manufacturing modules in an attempt to improve the accuracy of their databases. The collaboration software companies are also trying to build these links to improve the speed and availability of accurate shop floor data to customers and suppliers. Collectively, these efforts are often described as electronic manufacturing, or more commonly, "e-Manufacturing".

Even as the growth in the Enterprise Resource Planning and collaboration tool markets begins to wane, the new electronic manufacturing market appears poised for rapid expansion. This thesis demonstrates that the "bottom-up" strategy may prove to be more successful than a "top-down" approach in capturing market share. The most significant challenge for ERP vendors in developing e-Manufacturing solutions lies in the transactional nature of their software. Typically, updates occur on a daily basis, although many vendors are trying to reduce this to six-hour time segments. By contrast, control vendors commonly provide milliseconds of accuracy for process control. To provide "real-time" streaming data from the shop floor, certain control vendors appear to have a distinct advantage.

The developments in this thesis are built upon ABB's Industrial^{IT} technology. Given Industrial^{IT}'s ability to quickly integrate to a variety of data sources in real-time, e-Manufacturing related feasibility studies were conducted in four of ABB's facilities. Strategies for implementing these kinds of solutions successfully also appear in the last chapter.

1.2 ABB Evolves into an IT Solutions Provider

The merger of Asea and Brown Boveri in 1988 created one of the largest electrical engineering companies in the world. In the early 1990's, a combined ABB began to sell off it its heavier assets, such as nuclear power plants, power generation and rail businesses, to remain competitive and to open more opportunities for growth (Figure 1.1). Instead, ABB began to focus on electronics – such as automation (robotics, motors, consumer goods) and power technologies (distribution transformers, sensors, circuit breakers).

Through the 1990s, ABB made more than 50 acquisitions, particularly in the Automation Industry. One of the largest was the 1999 purchase of Elsag Bailey, valued at over $2 billion USD [17]. With an increasing product suite of control systems and hardware platforms gained by mergers, many of ABB's automation products could not communicate with each other effectively. They faced the challenge of remaining committed to customer support while avoiding significant investments in evolving separate, sometimes overlapping, systems.

Through the later acquisition of key software capabilities, ABB migrated towards the development of a single, common platform based on Microsoft COM technology. This solitary platform makes it possible for any piece of information to be available (in the right place at the right time, regardless of source) and to be fully integrated (the right data in the right combination, seamlessly integrated in real-time). This was the foundation for its *Industrial^{IT}* vision. By January 2002, ABB's expanded its "Industrial^{IT} enabled" product portfolio to nearly 3,000 products. In doing so, ABB saw that a strategic shift to IT Solutions would lighten their asset base and offered even further growth opportunities – much like a shift to Electronics from Electricity had accomplished years before.

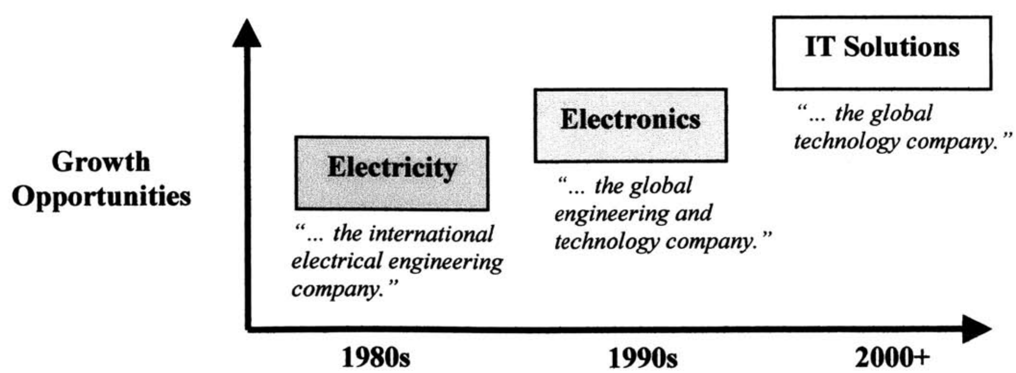

Figure 1.1 – ABB's Evolving Focus Based Upon Growth Opportunities as a Function of Time

As Industrial^{IT} began to take form, ABB found that they not only have the potential to deliver value at the device level, but that they might be able to expand into enterprise management functionalities as well. Thus, a new vision emerged to utilize Industrial^{IT} integrate an enterprise's automation, information and collaborative business systems together in real-time, as shown in Figure 1.2.

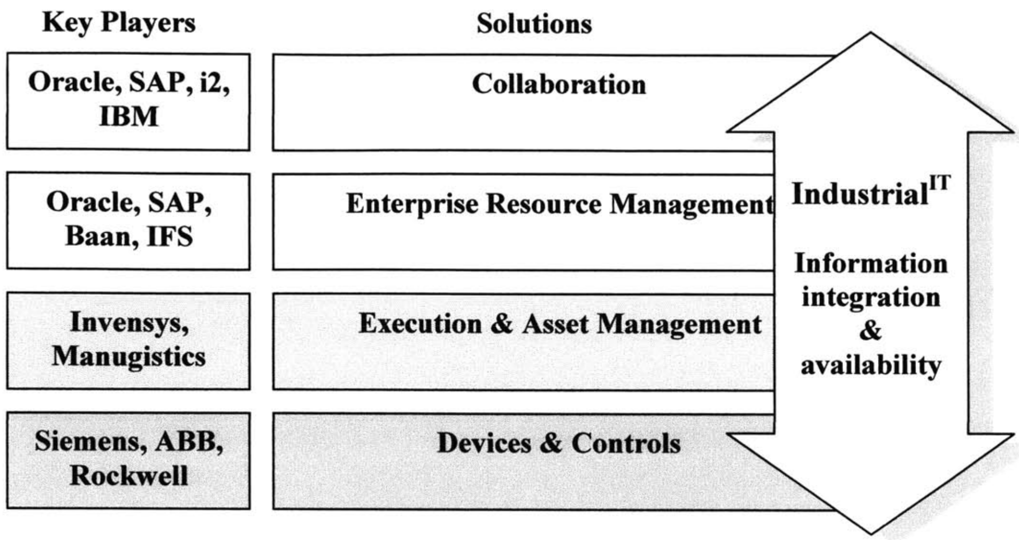

Figure 1.2 – Cross Enterprise Solutions, Key Players and the Role of Industrial^{IT}

Significant progress in 2001 targeted ABB's traditional customer market segments: pulp and paper (Södra pilot), petrochemicals (Pemex pilot), chemical process industries (Dow Chemical pilot), and power distribution (ABB Substation Automation). A common theme throughout these first projects is that they all serve continuous process industries, largely for process monitoring.

Despite ABB's interest in e-Manufacturing, an area not fully explored to date is the use of Industrial^{IT} to provide solutions in discrete-part manufacturing environments. This warrants further research because of the three hundred or more manufacturing and/or assembly facilities that ABB may be able to improve. As discussed in Chapter 4, opportunities in the external market also appear promising.

Acceleration of front-end processes started with the development of *Material Requirements Planning* (MRP) systems. This software stores information about customer demand, product variants and subcomponent relationships. By converting forecast to shop floor orders, this software helps produce master production schedules. Over time, MRP matured and improved while larger companies became more comfortable with using it. Enterprise Resource Planning software expanded upon MRP by including more features, such as capacity planning. Breakthroughs in Internet technologies in recent years have also spawned interest in collaboration software, such as *Supply Chain Management* (SCM) and *Customer Relationship Management* (CRM) tools. These tools are discussed in more detail in Chapter 3.

Acceleration of back-end processes followed a slightly different fate, however. Many attempts at achieving the *Computer Integrated Manufacturing* (CIM) vision failed miserably. To some extent, computers of the day did not have sufficient processing power, disk and memory size, or networking capabilities to operate effectively on the shop floor. They also could not easily handle the wide variety of custom protocols developed independently by separate automation controls vendors. A CNC machine, for example, may communicate via one of more than 4,000 protocols [23]. A more general problem was that CIM development was so focused on technology development that little attention was given to corresponding process development. As a result, wasteful processes became expensive, wasteful processes after adding computers to them. Eventually, the Japanese began to promote "lean manufacturing" which (in the roughest sense) emphasizes waste reduction over major investments in inflexible computer systems. As CIM fell to the wayside, manufacturing shop floors became a flurry of paper tags, rubber bands, paper-clips and Post-It notes. A view from a typical ABB plant is shown in Figure 1.3.

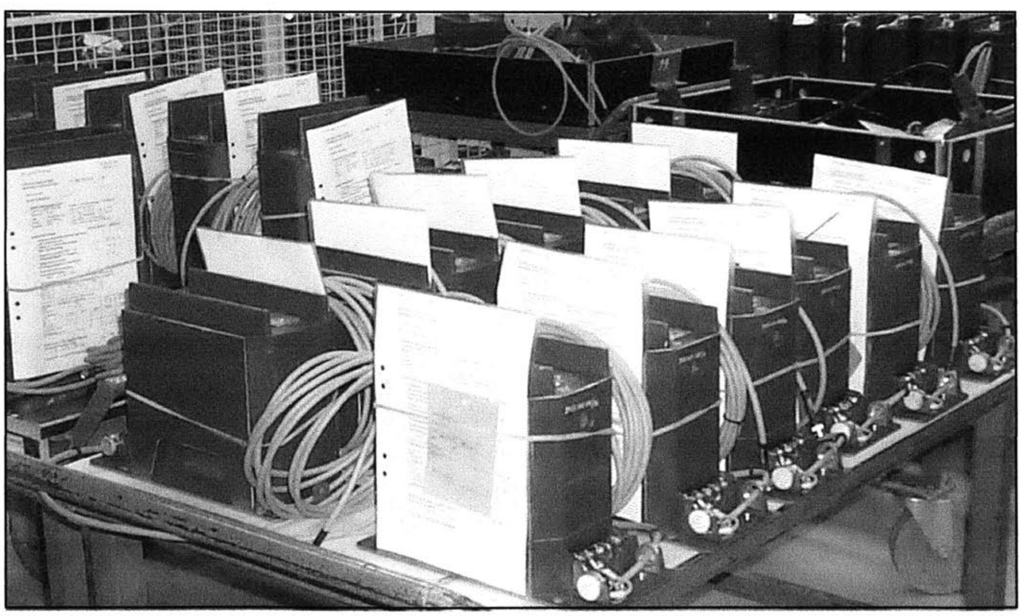

Figure 1.3 – Picture of Data Handling by Paper in a Typical Plant

With a platform designed for sharing information across many types of automation components, this work seeks to determine how to successfully fulfill an e-Manufacturing vision using ABB's technologies. The research is focused on the development of proof of concept models that utilize Industrial^{IT} for Shop Floor

Control and Manufacturing Execution System applications. Successful research here will enable major improvements to manufacturing capabilities, will provide key components for implementing e-Manufacturing strategies, and will open a large and dynamic new customer market for ABB to compete in.

1.3 Objectives

ABB's maintains Corporate Research Centers in 14 different countries. The Finnish Corporate Research Center (FICRC) in Vaasa, Finland is home to the Advanced Manufacturing Engineering group headed by Rafael deJesus. While tasked with manufacturing development and process improvement projects in facilities throughout several countries, AME has very few IT resources. Therefore, FICRC is not a development center for Industrial^{IT}. To determine how well Industrial^{IT} can be integrated with other discrete manufacturing projects, the objectives for this thesis include:

1) Investigating the capabilities of Industrial^{IT}
2) Defining the potential usage of Industrial^{IT} in discrete manufacturing environments
3) Planning and execution of several feasibility studies
4) Planning for future pilot projects
5) Identifying direction of future research

1.4 Scope of the Project

Due to the structure of the LFM internship, this research must be completed in only seven short months. Therefore, this research will likely serve merely as a precursor to additional work. Within the scope of this initial project is to investigating ABB's potential competitive advantages over other market players. Also, unique solutions relating to e-Manufacturing in discrete manufacturing will also be developed. Planning for future project deployment will be done. Significant travel is also to be expected to share the project's learnings with other groups (Helsinki, Stockholm, Västerås, Boston, Vaasa, etc)

1.5 Methodology

The methodology for completing the set objects within the scope follows this format:

1) Search available literature (internet, brochures, white papers) for competitive product offerings
2) Read background Industrial^{IT} materials - Attend training class in Ladenburg, Germany
3) Identify potential usage areas based on personal experience, and that of FICRC teammates

4) Attempt to model basic functionalities as Aspect Systems
5) Identify sites in Finland to do feasibility studies
6) Interview shop floor personnel, Program Managers and Management for ideas
7) Present results for various ABB groups, including the AWDC Conference in Västerås, Sweden
8) Plan for pilot projects in ABB plants by following the ABB Gate Model
9) Plan for future research opportunities

1.6 Structure of Thesis

This thesis is structured into seven chapters. Chapters 2 and 3 discuss the flow of information through the business process and attempts to integrate these functions by means of an e-Manufacturing strategy. Chapter 4 focuses on a particular area of e-Manufacturing, *Execution and Asset Management* (EAM), and outlines a business case strategy for a movement by ABB into this area. Chapter 5 provides a high level overview of technologies that ABB already possess. This is followed in Chapter 6 by specific case examples where ABB's technologies have been used to provide Execution and Asset Management solutions. Chapter 7 provides recommendations for successfully implementing the strategy outlined throughout this thesis.

2.0 MODELING THE BUSINESS PROCESS

2.1 Information Flow in Business is a Complex Network

Many causes of poor performance in a factory can be attributed to delays, complications, redundancies and errors in transferring information between different functional areas. By automating the links between nodes in this complex business process network, software may be utilized to improve many performance metrics as shown in Table 2.1.

Purpose of Automation	Effect on Business
Reduce Work In Progress (WIP)	Improves financial flexibility
Reduce production delay	Improves customer lead time
Reduce labor content	Improves customer value
Increase data accuracy	Improves cost accounting
Increase product visibility	Improves order tracking
Increase production flexibility	Improves responsiveness to market demand
Increase defect and delay visibility	Improves root cause analyses
Increase data accessibility	Improves business unit collaboration

Table 2.1 – Purpose and Effects of Automating Information Links Between Functional Areas

Typically, the standard flow of information in a manufacturing related business includes gathering *demand* requirements from the customer, transforming demand into *orders* for manufacturing, and turning orders into products which get sent back to the customer in the form of *shipments*. However, this flow is also affected by how the products are engineered and supported, how the resources are managed and strategic planning by the company. Many interrelationships between these functions also exist.

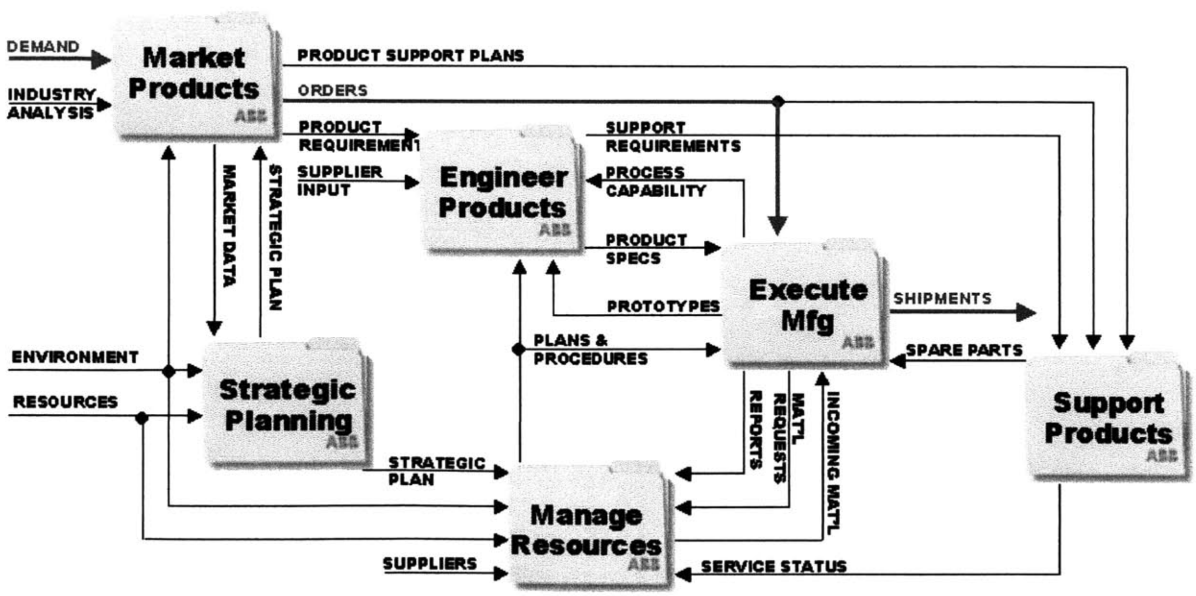

Figure 2.1 - High Level Overview of Information Flow in a Typical Business

Even at the high level overview shown in Figure 2.1, the complexity of business processes becomes apparent. Additionally, if you were to examine a particular functional area in closer detail, you would find an even more complicated sub-network of inputs and outputs. This is because there are many timescales on which different parts of the organization operates.

For example, the flow shown in the high level overview may be measured in terms of days and weeks. The flow of information in through manufacturing, which is the conversion of *orders* into *products*, may be measured in shifts and hours. The change in timescale represents the need to plan and schedule at a tactical level, the speed at which of supervisors must overcome problems with equipment or personnel, the manner in which subcomponent parts are supplied and the effects of improvements efforts made to products and processes by manufacturing engineers.

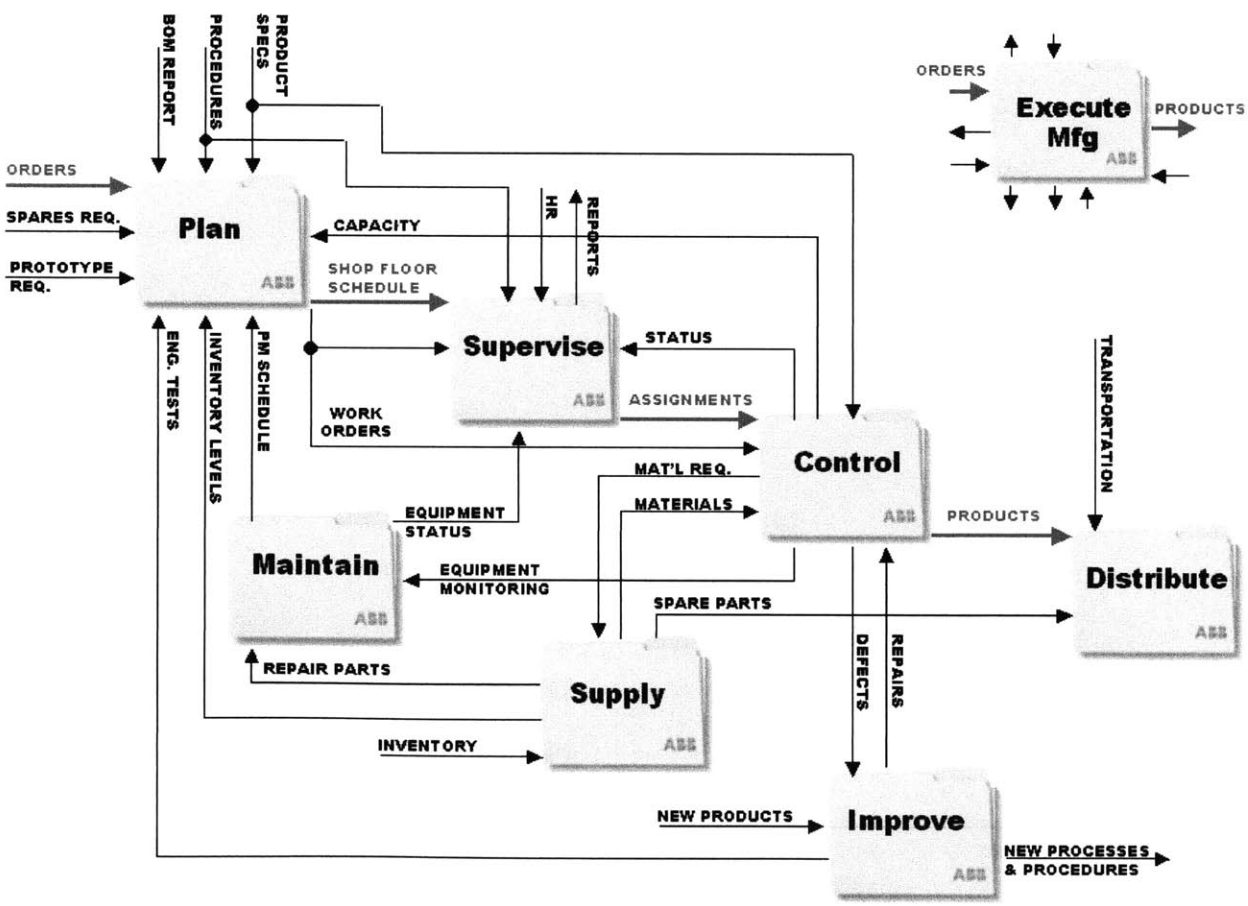

Figure 2.2 - Mid Level Overview of Information Flow Through Manufacturing

It is a non-trivial exercise to take a shop floor schedule and issue work assignments because there are many real life issues to take into consideration. For example, process variability can change work center throughput, suppliers can deliver late or incorrect parts, workers may be absent, equipment may be under repair and certain orders may require special instructions from engineering. As such, few processes rely solely on one input and produce one output. Therefore, it is necessary when examining a particular area in the production process to break down the information flow into a set of inputs and outputs. At this basic level, the timescales may be in minutes, seconds or even milliseconds.

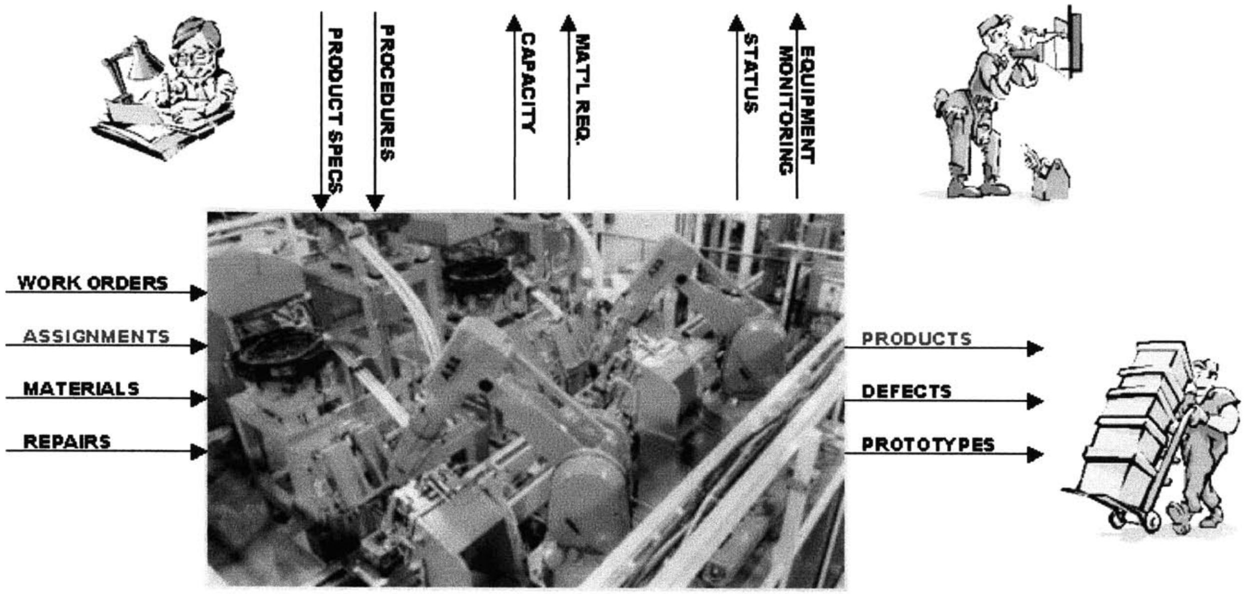

Figure 2.3 – Low Level Overview of Information Flow Through a Work Cell

Before the widespread use of computers in business processes, people handled these network links manually. Today, some processes are highly automated while many others are still done by hand. A key disadvantage to manual processing is that it is usually less efficient and more prone to error than properly automated processing. Also, employees often receive incentives to optimize locally instead of globally. Relatively few people can visualize the "big picture" of the entire process. Therefore, as computers become less expensive and more powerful, companies increasingly use them to automate parts of their business processes.

2.2 Software Applications Are Tailored to Automate Many Processes

There is no shortage of business related software available from marketing and brand management to customer service and support. An exhaustive web search of business software found more than 8,500 processes that have computer applications associated with them. For a condensed listing of major application functionalities, refer to Appendix A. These processes can be roughly grouped into seven major categories, as listed in Table 2.2.

Customer Relationship Management	Process Management
Supply Chain Management	Manufacturing Management
Business Management	Quality Management
Plant Management	

Table 2.2 – Major Categories of Business Applications

As an example, Plant Management (the smallest group) has three major subsections: Resource Management, Maintenance Management, and Finite Scheduling. The Maintenance Management subsection contains many types of applications, including: Work Order Management and Reporting, Maintenance Resource Tracking and Control, Equipment History, Purchasing and Service Contracting, Preventative Maintenance Scheduling, Spare Parts Inventory and other support functions. Other categories cover a broader scope of functionalities.

While not every application can be shown conveniently in a single figure, the most common applications are arranged in Figure 2.4 below. This diagram was created for this project in order to map out competitive software offerings by several companies and to illustrate where key links between software packages may be missing.

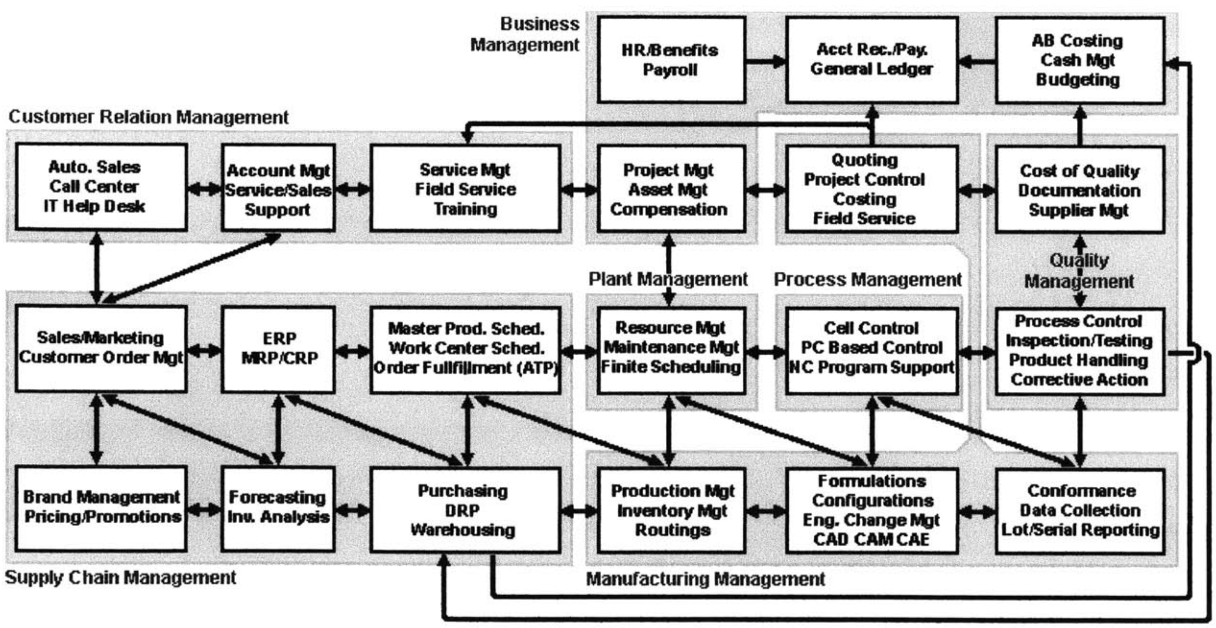

Figure 2.4 - Business Application Functional Topology

By mapping out software applications by function, one can avoid the complicated overlapping of three and four letter acronyms used by different companies to market their solutions. For example, those Maintenance Management functionalities discussed above may be included in EAM (Enterprise Asset Management) solutions, PAM (Plant Asset Management) solutions, MES (Manufacturing Execution System) solutions, or CMMS (Collaborative Maintenance Management Systems) solutions. The problem is that there are literally thousands of companies producing niche software in different parts of this diagram without agreeing to a standard nomenclature.

However, many companies use some basic form of hierarchy from the enterprise management level to the device level, as discussed in Chapter 3. At the top is collaboration software (Customer Relationship Management and Supply Chain Management), followed by Enterprise Resource Planning systems (ERP), then Manufacturing Execution Systems (MES), Shop Floor Control systems (SFC, or sometimes SCADA), and finally Device Automation. The ability to integrate these software functionalities often forms the basis for a vision / strategy called e-Manufacturing.

2.3 Chapter Summary

A highly complex, interdependent network of information flows can model the manner in which companies satisfy customer demand. Some of these flows are handled at a strategic level, some at the tactical level and others at the operational level. As a result, automated links must operate at many different timescales. Delays, errors and disruptions in these flows are the source of many ill side effects, including higher costs, longer lead times, increased inventories and lowered quality. Inefficiencies and errors are often introduced by manual transaction handling, thus many software companies are trying to develop automated solutions. There is a significant amount of confusion and overlap in the naming conventions for these software applications. This chapter presents a framework for modeling applications by function. The major functional areas include Customer Relationship Management, Supply Chain Management, Business Management, Plant Management, Process Management, Manufacturing Management, and Quality Management. (Additional details can be found in Appendix A). The next chapter outlines the typical strategy for integrating the software functionalities at the Device level to the systems at the Enterprise Resource Planning level; a strategy often called e-Manufacturing.

3.0 E-MANUFACTURING OVERVIEW

3.1 e-Manufacturing is Difficult to Define

By reading the marketing literature of many predominant companies, one might be led to believe that *the* key to maintaining competitive advantage in recent times is through the development of "shop floor to top floor" style information systems. (The expressions "sensor to boardroom" and "factory floor to executive door" are also popular). Systems that attempt to interface more traditional business systems (i.e.: Enterprise Resource Planning systems, Customer Relationship Management tools) to back shop operations (i.e.: automation, machine controllers) using the Internet or other IT technologies are often referred to as part of an "e-Manufacturing" strategy. The small "e" in e-Manufacturing is in reference to an *electronically enabled* system, much in the same way e-mail, e-Commerce, and e-Business have become popular expressions. The purpose of electronically enabling manufacturing operations is to eliminate manual processes that are labor intensive, non-value added or error prone, and to create synergies through the sharing of data.

In truth, e-Manufacturing accomplishments in most companies are largely unrealized upon closer inspection. For example, a major corporate initiative at Intel is its "Edge To Edge" program, envisioned to provide perfectly streamlined data handling from customer order through distribution. Thus far, the technology leveraged continues to be based upon a loose collection of hundreds of Excel spreadsheets spread around the world. It is hard to determine whether this initiative can be classified as a true e-Manufacturing implementation or not because e-Manufacturing is itself difficult to define.

In its roughest form, e-Manufacturing is a collection of methodologies, technologies and strategies that link islands of automation together. The ARC Advisory Group believes that optimized e-Manufacturing systems should endeavor to fulfill seven basic functions [9]:

1. **Synchronize Production Processes With Business Processes.** This is accomplished by exposing the data from the shop floor to high-level systems. Reporting the actual status of the shop floor back to an Enterprise Resource Planning system, for example, helps validate assumptions on lead time and keeps actual and theoretical inventory levels in check.

2. **Orchestrate the Upstream Flows Of Work, Information and Material**. In reverse, by linking into supply chain and other upstream data the shop floor is able to become more flexible and produce to demand instead of to forecast.

3. **Automate Business Processes And Workflows Within the Enterprise and Across the Value Chain**. Because of the increasing pace of business, manufacturers have less time to generate a plan in advance and to simply monitor the progress of work than they did before. Now the strategy is to respond quickly to changes in demand and supply and then react appropriately. Thus, automating key business processes is becoming a competitive weapon.

4. **Give Control to Managers with Plant Information and Analysis Tools**. New Internet based tools are available on a continual basis allowing managers to aggregate data from a variety of sources. Additional functionality is helpful to take performance metrics and interpret complicated relationships.

5. **Integrate the Design Process Among All Collaborating Parties**. Using e-Manufacturing tools to accelerate the production of existing products is a temporary advantage unless similar focus is given to accelerating new products as well.

6. **Leverage Bi-directional Downstream Information**. With synchronized processes in place within the plant, the information from the shop floor (quality, lead time, etc) and information from the business systems (orders, inventory, etc) can be leveraged out into other functions. For example, marketing staff can be armed with knowledge that guarantees more accurate Available To Promise dates.

7. **Enable Collaborative Maintenance and Manufacturing Support**. By sharply increasing responsiveness, the effects of equipment failure or other downtime can be quickly felt by the customer. Consideration to prevention, monitoring and information sharing between sites should be an important aspect to keeping processes running smoothly.

While many of these activities appear to be logical strategies to implement, e-Manufacturing projects are often difficult for companies to justify. A significant challenge is that Return on Investment for these types of implementations can be poorly defined because they typically do not have concrete start and stop dates [6]. Another challenge is that manufacturing companies seldom have the technical expertise to integrate their operations. Therefore, to deliver such functionality, one must first understand how various types of information systems fit together with each other.

3.2 The Information System Topology is Often Shown on Four Levels

Within the broad scope of Information Systems there are a very large number of software companies offering different sets of software suites. Some offerings are a response to the recent influx of automation equipment into modern factories. Some of them respond to a local need for control and/or optimization of a particular type of equipment, or address a particular manufacturing concern such as statistical process control or operator interfaces. Others attempt to resolve global manufacturing concerns such as tracking total factory performance. Commonly, the hierarchy of software solutions used for e-Manufacturing can be characterized by linking the four categories shown in Figure 3.1 together. For a complete picture of all information systems, refer to Figure 2.4.

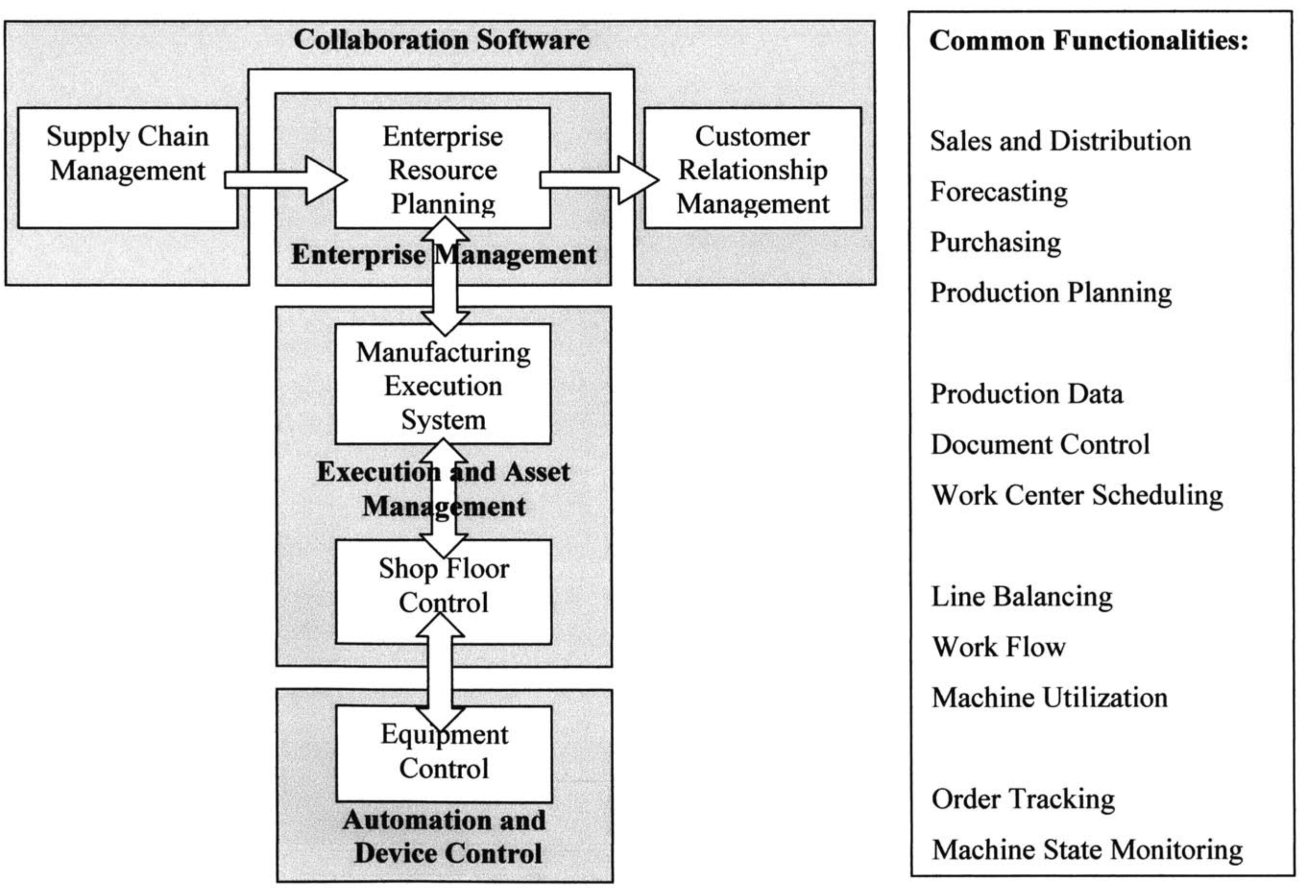

Figure 3.1 - Common e-Manufacturing IT Topology

1. **Collaboration Software:** There are two types of collaboration software, buy side software and sell side software. The buy side software is often called Supply Chain Management (SCM). The sell side software is usually referred to as Customer Relationship Management (CRM). Manugistics and i2 are some of the largest players in this segment.

2. **Enterprise Management:** This is the largest segment of commercially available IT solutions today. It includes the Enterprise Resource Planning, ERP II, and Material Requirements Planning software as well as other broad scoped software suites. The major players in this field are Oracle, SAP, and Baan. There are also many smaller players, each trying to carve out a niche. The larger players have attempted to leverage their software to move into other categories. They have seen only limited success thus far.

3. **Execution and Asset Management:** This segment includes both Manufacturing Execution Systems and Shop Floor Control Systems. (Another widely used term is SCADA - Supervisory Control and Data Acquisition). Many companies offer software that monitors and controls a particular area of a factory. Some control a particular brand of tool, others a group of similar tools, while others control entire work cells. Other companies address a particular issue, such as batch control or ordering processes. However, they generally don't talk to each other. The practice of piecing these together is the heart of Manufacturing Execution Systems (MES). Players in this category include Wonderware, Foxboro, Honeywell, Invensys, and Intellution.

4. **Automation and Device Control:** These are the actual control modules connected to the factory machines. Drivers are written and downloaded into controllers such as the common Programmable Logic Controller (PLC). These devices are implemented at very lowest level of floor control; they send the commands to the machines that build the parts. Often, this software is provided with the hardware by manufacturers, such as Allen Bradley, Siemens and MDSI.

3.3 Supply Chain Management Tools Increase Cash Flow

According to white paper by deJesus, Supply Chain Management tools add value by decreasing transactions costs in the procurement of materials, reducing logistics expense and decreasing inventory levels. This can be done through linking customer demand directly to procurement, increasing the effectiveness of selecting suppliers, sharing information with suppliers and improving the accuracy of forecasts to reduce slack [6].

Without SCM tools, a number of procurement problems are not easily solved. For example, it is nearly impossible to analyze spending trends across an entire large enterprise. It can be difficult to identify the potential components and suppliers at the lowest possible prices. Request For Quote processes are both cumbersome and time consuming. Traditional tools deal with complexity by maintaining high levels of inventory, and may even utilize different part numbering schemes than those used in production.

These issues stem from a variety of reasons. Often, growth by mergers and acquisitions results in many independent but redundant purchasing functions. In larger companies, there are few mechanisms to provide visibility of suppliers across the enterprise. Without IT, purchasing agents do not have access to collaborative mechanisms, such as auction tools. They also have very limited feedback from the shop floor to help set appropriate levels of WIP to meet customer demand.

Supply Chain Management software enables requisition automation, collaboration and evaluation of RFQs and the rationalization of catalogues across multiple divisions. Online reverse auctions and bid analysis tools are now available. Companies also have the capability to model multi-enterprise information flow. As a result, Supply Chain Management procurement tools result in:

- Reduced inventory levels
- Decreased procurement cycle times
- Better price, term and delivery agreements
- Aggregation of spending across divisions with fewer / better suppliers
- Improved time to market with new products through collaboration with suppliers
- Improved supplier performance (i.e.: shorter delivery to pay cycles)
- Scenario / "what-if" analyses

Another value proposition of Supply Chain Management is reducing the costs of logistics and distribution. Without software to aid in planning and optimization of transportation, both internally in manufacturing and externally for sales, a company can overspend on labor and shipping or store too much safety stock. Even when companies tie up extra working capital in inventory, then cannot prevent stock-outs, obsolescence, and excess expediting. Aggravating factors include lack of visibility in the supply chain, poor capacity management among trading partners, inaccurate forecast models, and demand spikes or variance. SCM enables shipment optimization and true cost calculation, strategic capacity placement, and assessment tools for trading off service levels and inventory. Supplier collaboration can lead to better delivery time reliability, reducing a dependence on safety stocks. Also possible are real time supply chain visibility and monitoring, and dynamic sourcing. Real time visibility results in:

- Reduced inventory carrying costs and capital expenditures
- Reduced transportation costs
- Increased levels of customer service
- Maximized profitability
- Reduced indirect labor and surcharges (i.e.: costs associated with expediting)

3.4 Customer Relationship Management Tools Improve Customer Value

The purpose of Customer Relationship Management tools is to provide better value to the end customer by being more responsive and flexible. Three major deliverables outlined in the deJesus report [6] are:

- Extending the flexibility of agile manufacturing to the customer
- Increasing visibility in the ordering process
- Improving forecasts by increasing customer understanding

Order handling, including obtaining, quoting, processing and completing, can add up to several days to the total product lead time. Part of the problem is attributed to incomplete or outdated order data from the customer that has to be followed up on. This can be caused by outdated catalogues and price lists which cannot be updated rapidly. Another problem is that the order must be re-entered into several separate business applications. Therefore, the cost of indirect labor to this may be quite high, and at the same time be difficult to track to specific products. Delays in closing orders also impede cash flow.

Many companies quote standard lead times instead of evaluating their actual current manufacturing capability. This is done in order to protect "% On Time Delivery" figures and because the salesmen may not have visibility to the shop floor. As a result, a company may actually lose revenues because those standard lead times may be unacceptable to certain customers.

Using modern technology, order processing can be largely automated to compress lead times and to reduce redundant data re-entry. Companies can add value to their customers by providing up-to-date inventory and pricing levels (Available To Promise), while reducing the cost of printed sales materials.

They also add value by considering the capacity of different work centers (Capable To Promise) yielding in more precise expected delivery dates. Other means to increase revenues based on individual customer profiles include up-selling, cross-selling and dynamic pricing. In some cases, personalized service creates higher switching costs that help to lock in customers.

Customer Relationship Management tools may also be used by the customer to assist order entry. Selectica, for example, provides software that allows end users to configure product and delivery options online. If successfully tied to back-end operations, this information could dramatically improve production scheduling. By linking CRM to customer care, FAQ (Frequently Asked Questions) documents, online support and documentation services, companies can reduce call volumes and care requests to customer call centers [6].

3.5 Enterprise Resource Planning Systems Integrate Manufacturing Functions

Enterprise Resource Planning systems are designed to integrate the operational functions of a plant by providing top-down planning. They are particularly useful for useful for discrete manufacturers with extended Bills of Materials [12]. In the 1960s, Material Requirement Planning systems were developed whose core functionalities included:

- Production Definition – This database stores information about raw materials, purchased parts, manufactured parts, subassemblies and finished goods. This includes the relationship between the items, plus their estimated cost, lead-time, quantity, and order information.
- Material Control – This function provides inventory control by recording material transactions and storing a running balance.
- Material Planning – This function evaluates the forecasted demand versus the available supply to produce a master schedule.

In the 1970s, Distributed Resource Planning (DRP) was developed to handle the steps from the end of the assembly line through delivery of the product. In the 1980s, the MRP systems began to link with the financial and accounting functions, which they called MRP II [23].

Enterprise Resource Planning additions in the 1990s to the basic MRP II platform have included the ability to generate shop floor reports, to track work order status, to handle Capacity Requirements Planning and to store routing definitions. Process definition, human resources, marketing, finance, purchasing and distribution modules have also been developed [1].

However, the reason that some Enterprise Resource Planning systems are underutilized or fail to capture a solid return on investment lies in some problematic, basic assumptions. First, the underlying Material Requirement Planning algorithm assumes infinite capacity at the work centers. Second, MRP assumes fixed lead times. Finally, data from the shop floor is not automatically reflected in the MRP system in real time. These links to shop floor data were poorly defined because MRP was not initially intended for use on the factory floor [23]. Therefore, many of the shop floor functionalities often have troubles, including: incorrect material information, outdated time standards, unrealistic lead-time assumptions and poor micro-scheduling [12].

3.6 Execution and Asset Management Systems Provide Real-Time Visibility and Control

MESA International, an association of Manufacturing Execution System vendors, defines Execution and Asset Management (EAM) systems as those that:

> "...deliver information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, [EAM] guides, initiates, responds to, and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non value-added activities, drives effective plant operations and processes. [EAM] improves the return on operation assets as well as on-time deliver, inventory turns, gross margin, and cash flow performance. [EAM] provides mission-critical information about production activities across the enterprise and supply chain via bi-directional communications." [8]

Execution and Asset Management (including Manufacturing Execution Systems) applications typically include some or all of the following functionalities listed in Table 3.1.

Resource Allocation / Status	WIP Status / Traceability	Performance Analysis
Labor Management	Process Management	Quality Management
Product Genealogy	Operations Scheduling	Data Collection
Document Control	Production Dispatching	Maintenance Management

Table 3.1 – Twelve Functionalities of Execution and Asset Management Systems

The benefits of Manufacturing Execution System implementations were studied in several surveys during the 1990s [15]. The major improvements cited are included in Table 3.2.

Reduced total lead times	(average 22%)
Reduced manufacturing cycle time	(average 35%)
Reduced work in progress (WIP)	(average 32%)
Reduced defect rates	(average 22%)
Reduced or eliminated data entry time	(average 75%)
Reduced or eliminated paperwork between shifts	(average 67%)
Reduced or eliminated lost paperwork	(average 55%)

Table 3.2 – Survey Results on the Effects of Manufacturing Execution Systems

The reduction of lead times, inventories and defect rates are the same goals that the Advanced Manufacturing Engineering group in the Finnish Corporate Research Center (FICRC) traditionally aim to achieve in their projects. Therefore, the Execution and Asset Management area is the most interesting area to explore among the many areas where Industrial^{IT} might be applied.

3.7 ERP-EAM Linked Systems Create a Powerful Combination

The research in this thesis is intended to investigate the use of ABB's Industrial^{IT} technology to build Execution and Asset Management style applications. This does not suggest that these developments are intended to replace Enterprise Resource Planning functionality. Quite to the contrary, linking the real-time shop floor system to a transactional-based planning system creates an effective, bi-directional combination as shown in Figure 3.2 [12]. In one example, the combination of ERP and EAM at Boeing saved well over $100 million dollars alone on their C-17 cargo plane plant in Long Beach, CA [5].

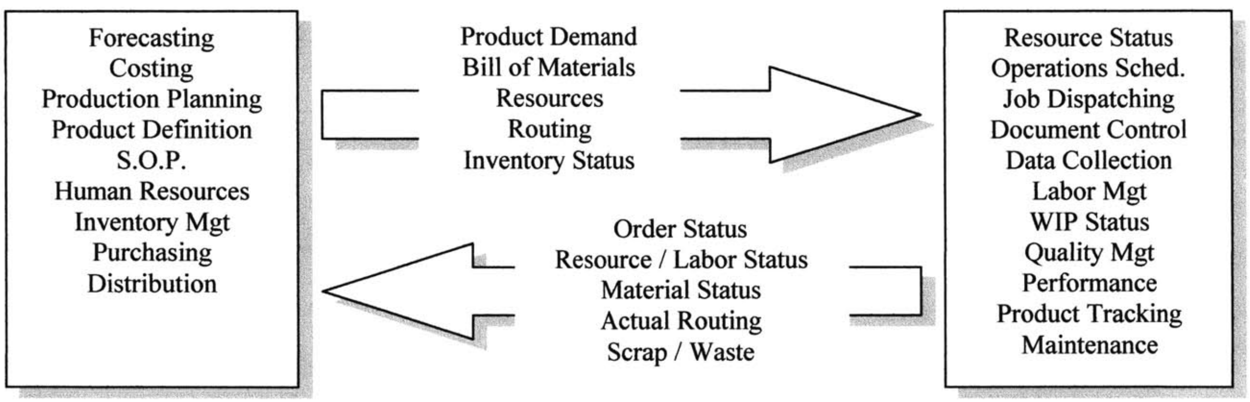

Figure 3.2 – Bi-Directional Data Flow Between ERP and EAM Systems

3.8 Chapter Summary

e-Manufacturing programs support the integration of business processes with production processes, coordinate the flow of work and material across the business and its value chain and reinforce collaboration with suppliers and customers. Developing these linkages can be a large challenge and true progress is commonly over-stated by companies. In addition, calculating the return on investment of an e-Manufacturing implementation is difficult because it may be poorly defined and may not have concrete start and stop dates. This chapter also provides an overview of the four common abstraction layers on information systems from the "shop floor to the top floor", including Collaboration software (Customer Relationship Management and Supply Chain Management), Enterprise Resource Planning software, Execution and Asset Management software, and Automation and Device Control software. The next chapter discusses the market opportunity for ABB to deliver value at the Execution and Asset Management layer.

4.0 MARKET OPPORTUNITY FOR EXECUTION AND ASSET MANAGEMENT

4.1 Execution and Asset Management Offers Growth Opportunity

Enterprise Resource Planning (ERP) has been a thriving business over the last several decades. Although it continues to overshadow many other areas, at $5.53 billion USD realized market value in 2001 [23], the market is nearing maturity and saturation. Many sources expect the ERP market to gradually slow to less than 5% compound annual growth. As Internet technologies have matured, Supply Chain Management (SCM) software on the buy side and Customer Relationship Management (CRM) software on the sell side have also grown. These segments should continue to expand between 12-18% compound annual growth for the next few years before also leveling off.

Recent developments in software architecture and network technologies have opened the doors to manufacturing integration. The manufacturing community is looking to leverage their ERP systems to improve the integration of manufacturing into enterprise planning. At the same time, communication protocols such as OPC (OLE for Process Control), BACnet and LonWorks are driving the use of standard interfaces between hardware controllers and system management software. Advancements in IT infrastructure and technology have finally created the necessary environment for the vision of the Computer Integrated Manufacturing and Manufacturing Execution Systems strategies to reach their full potential. Mike Burkett, senior analyst, aerospace and defense, at AMR Research notes [14]:

> "There is a real opportunity here for MES vendors. What it comes down to is there's a real gap that needs to be filled. Many manufacturers are using big planning engines to create a schedule that gets killed when something changes on the floor. To close the loop and respond efficiently to change, manufacturers need tight integration between the real-time shop floor information captured in the MES, and the big enterprise systems."

When this research started, ABB was already focused on expanding their solution offerings into the EAM level from the Controls level. However, most of the pilot projects for Industrial^IT development were focused on the utility and process industries. ABB has started projects in pulp and paper mills (Södra), oil refineries (Pemex), chemical processing plants (Dow Chemical), and is active in electricity distribution and substation monitoring. Only one proposal to use Skyva and AIP to totally integrate an ABB assembly plant from "receipt of order" to "delivery of product" had been accepted by July, 2001. The reason for this is that the process industry market segments represent a large majority of ABB's end customers whereas the discrete "customers" are predominantly internal facilities.

Market research from the Gartner Group [22], the ARC Advisory Group [10], and from Frost and Sullivan [21] all show that worldwide spending on "Manufacturing" related software is significantly higher and growing faster than on Utilities and related process industries. This suggests that there is great potential for ABB to develop e-Manufacturing solutions for this external market, as well as to serve its traditional customer base.

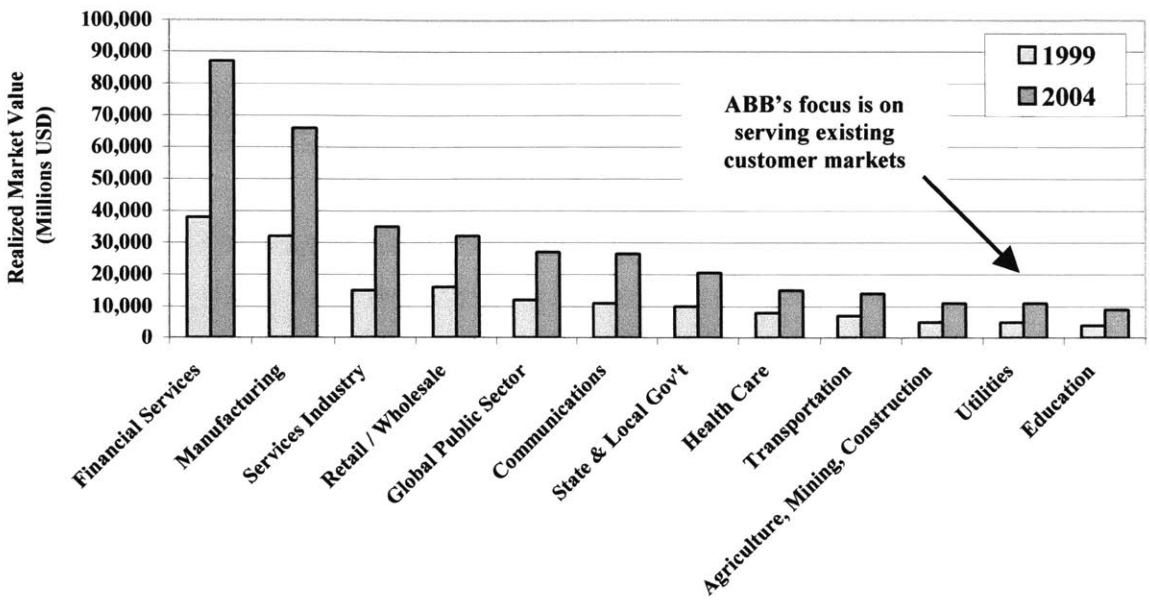

Figure 4.1 – Worldwide Software Spending in 1999 and 2004 Forecast by Vertical Market

This chart is difficult to interpret on its own because many ERP vendors provide both Financial Services and Manufacturing functionalities. To segment the Manufacturing related software market further, Table 4.1 lists market size estimates from a number of established sources. Of particular interest, Frost and Sullivan reports that the Execution and Asset Management market segment had a realized market value of $1.55 billion USD in 2001. (Unrealized market potential: $5.50 billion USD). This estimate includes Manufacturing Execution Systems and SCADA (Supervisory Control and Data Acquisition) systems, but excludes Software Control and Hardware Infrastructure. The report suggests that market growth will start around 15% per annum and will grow to 20%, slowed initially in part by "socio-cultural barriers to the adoption of technologies that necessarily bridge long standing departmental and professional barriers in heavy industry" [23]. The ARC Advisory Group indicates that the "discrete" segment of the Execution and Asset Management market is currently over $400 million USD with a compound annual growth rate of 20%. Expected growth through 2008 is plotted in Figure 4.2.

Market Segment	Market Size	Growth Rate	Dated	Source
World Wide Software Spending (Entire)	160 Billion	19% CAGR for 5 years	1999	Gartner Group
World Wide Software Spending in the Manufacturing Industry	32 Billion	19% CAGR for 5 years	1999	Gartner Group
World Wide Enterprise Software Spending	10 Billion	19% CAGR for 5 years	1999	Gartner DataQuest
World Wide ERP Software Spending	5.53 Billion	10% CAGR	2001	Frost & Sullivan
Execution and Asset Management software	1.55 Billion	15%-20% CAGR	2001	Frost & Sullivan
Software Spending in Collaborative Production Management (CPM)	1.2 Billion	13% CAGR for 5 years	2000	ARC Advisory Group
CPM software specific to Discrete Manufacturing	400 Million	20% CAGR for 5 years	2000	ARC Advisory Group

Table 4.1 – Market Segmentations of Manufacturing Related Software from Several Sources

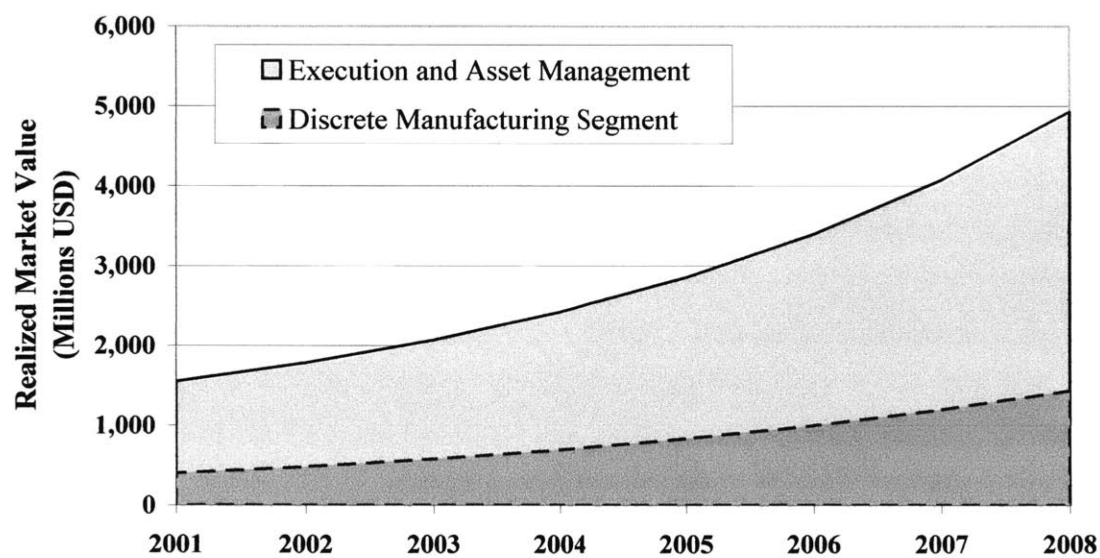

Figure 4.2 – Expected Growth for Execution and Asset Management, 2001-2008 (Millions USD)

Perhaps the most interesting aspect of the Manufacturing related software market is that roughly two-thirds of the total available market share is held by companies who individually own less than 2-3%, as shown in Figure 4.3 [19]. Many of the companies in the MES space in particular are only between $5-$20 million in revenues [23]. Certainly, the biggest players are the ERP vendors who are trying to push down into this space by offering add-on modules for manufacturing. Also in this space are larger automation component suppliers who are developing higher-level application layers to their proprietary systems [27]. A listing of key companies and their technologies can be found in Appendix B.

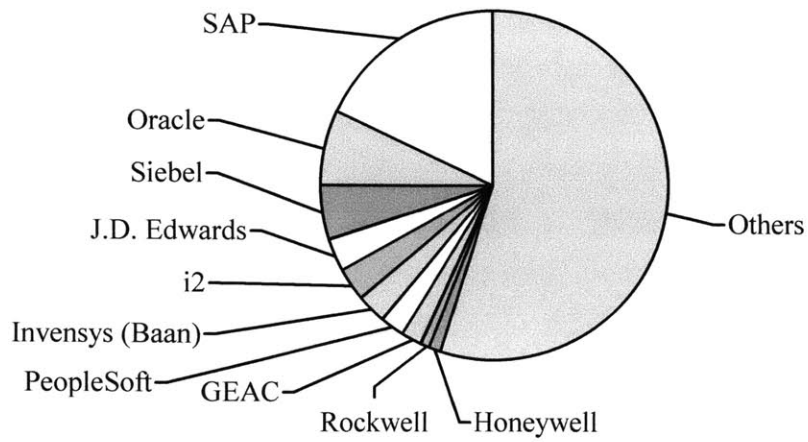

Figure 4.3 – Manufacturing Related Software Market Share, 1999

The Execution and Asset Management market offers significant growth opportunities because the realized market value is large, with even higher unrealized market potential and strong growth, and because there are no significantly dominant players taking all of the market share. Further, the market is relatively new (approximately 5 years old) although the technologies used are established [23].

Given ABB's expansive domain experience in automation, their positive reputation for providing solid turn-key based systems, and their new Industrial^{IT} technology designed to integrate "islands of automation", the company is well positioned to usurp market share from a large number of smaller players. An independent review by the ARC Advisory Group reports that ABB's Industrial^{IT} platform is several years ahead of its closest competitors. While other "wrapper" systems exist to display data from several sources in one application, ABB's software is far ahead in its ability to integrate those sources and to provide tools that speed up development and deployment [17]. Further, ABB is a leading supplier of instrumentation and drives which enables opportunities to cross sell Execution and Asset Management solutions with tightly integrated automation products.

4.2 Execution and Asset Management May Growth Larger Than ERP

As mentioned, the Enterprise Resource Planning market that had enjoyed significant attention and spending in previous decades is not growing as steadily any more. Some reasons for this include:

- Recent highly publicized reports and case studies that ERP systems show that they seldom achieve their return on investments [2]. Some parts of ABB are even prohibited from requesting investments in ERP

- Establishment of dominant designs by SAP, Baan and Oracle dropped many weaker, lower cost competitors out of the marketplace making ERP less affordable for smaller manufacturers
- ERP vendors have failed to integrate their transactional based systems effectively with real-time enterprise asset management systems
- The all-or-nothing ERP approach to implementation drives installation costs phenomenally high

Execution and Asset Management systems can be much less complicated to build and install than other types of systems. ERP maintains large databases, SCM utilize complex algorithms and CAD/CAM systems require high overhead graphics capabilities [8]. If done intelligently, an EAM system can be built from smaller functional pieces. This introduces less risk and investment on a per solution basis, than a monstrous single piece of software intended to control everything. For example, a plant could first install a maintenance management solution and test it until they are comfortable. Then they might integrate a material handling solution for the stock room. Later, paperless work instructions could be developed followed by production micro-scheduling [11]. As you will see in Chapter 5, this is exactly how Industrial^{IT} can be scaled into a complete e-Manufacturing solution.

4.3 ABB's Implementation Strategy is to Leverage Self-Improvement Opportunities

In order to develop Execution and Asset Management skills for discrete manufacturing, ABB has started by targeting solutions around their own factories. A survey of 99 factories from five of ABB's divisions shows the incredible diversity of manufacturing sites available internally (Table 4.2). Solutions for high volume and low volume production could be investigated, in both large and small facilities. The average performance for these plants is also less than world-class targets meaning that ABB would benefit financially from deploying solutions internally.

Metric	Min	Avg	Max	World Class Target
Hourly Employees	2	195	1450	-
Volume (# of units)	10	3.2M	165M	-
Lot Size	1	53	500,000	(1)
Throughput	2 wks	Varies	60 wks	Days
Inventory Ratio	3%	16%	50%	1-2%
Capacity Utilization	16%	73%	115%	70-80% (7d/24hr)
Delivery Promptness	0%	85%	100%	99+%

Table 4.2 – Metrics Measured at 99 Factories Within ABB

More than 300 facilities internal to ABB either manufacture or assembly products discretely. Further, incentives could be created for implementing Industrial^{IT} at these sites without the risk of losing goodwill from external customers due to unsuccessful early installations. Therefore, a possible implementation scenario might be to test out several pilot projects within ABB through 2003, and then begin to offer solutions externally, as shown in Figure 4.4.

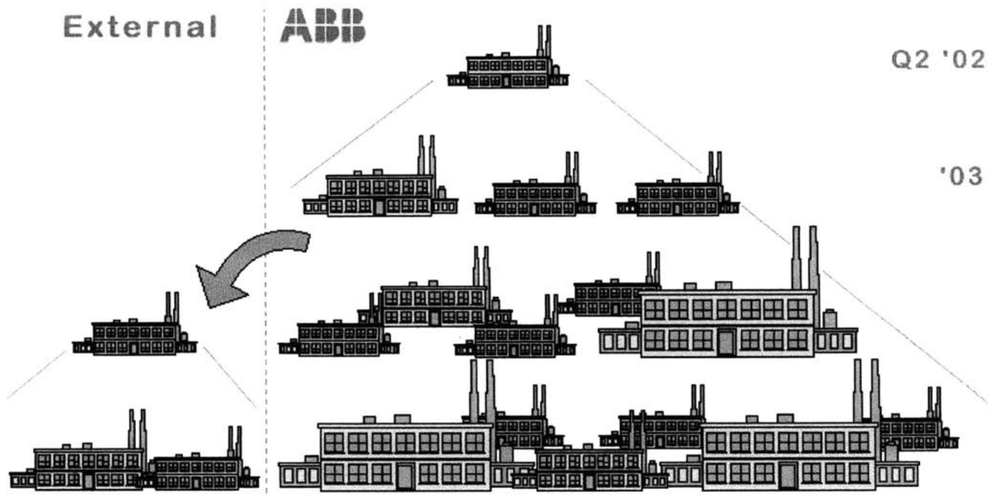

Figure 4.4 - Potential Deployment Plan For 2002 and Beyond

A Frost and Sullivan report published during this thesis suggests the primary market areas most impacted by the development of Execution and Asset Management systems (Table 4.3) [23].

Industrial Area	6 Months	1-2 Years	3-4 Years
Industrial Components	High	High	High
Automotive Assembly	High	High	High
Electronics	High	High	High
Computer Industry Components	High	High	High
Magnetic Media (Computer)	High	High	High
Aerospace / Defense	High	High	High
Semiconductor Industry	High	High	High
Apparel	Moderate	High	High
Food / Beverage	Moderate	Moderate	High
Rubber / Plastics	Moderate	Moderate	High
Medical Devices	Moderate	Moderate	High
Chemical / Pharmaceutical	Low	Moderate	High
Petrochemical / Oil & Gas	Low	Moderate	High
Pulp / Paper	Low	Moderate	Moderate
Building Materials	Low	Moderate	Moderate
Metals	Low	Moderate	Moderate

Table 4.3 – Primary Market Areas (Worldwide) and the Impact of EAM

As discussed in the beginning of this chapter, ABB's focus has been on chemical processing, petrochemicals, and pulp and paper representing their major customer segments. As shown on Table 4.3, Execution and Asset Management may be low to moderate impact on these market segments for the next two years. However, ABB itself is a discrete manufacturer of electronics and industrial components, areas likely to be highly impacted by EAM. This further validates the strategy to deploy solutions internally for a short time before approaching the external market.

4.4 Chapter Summary

While the Enterprise Resource Planning market has become matured and saturated, the Execution and Asset Management market has only recently emerged. Because EAM is built upon standard technologies and is being pushed by both the ERP players and the Control players, significant growth can be expected for several years. Execution and Asset Management solutions are implemented in a less-risky and more cost efficient manner than Enterprise Resource Planning. Therefore, EAM may eventually outgrow the ERP market size. By widening their scope to include discrete manufacturing, ABB may also uncover more exciting opportunities than by solely developing solutions for utilities or process industries.

No established dominant design or major player exists in the Execution and Asset Management segment to date. Therefore, there is a good opportunity to take market share from many smaller players. ABB in particular has the prerequisite abilities to dominant in this space, given their experience, reputation and Industrial^{IT} technology. A potential implementation strategy would be for ABB to develop pilot projects internally for a short while before offering solutions on the open market.

5.0 INDUSTRIAL^{IT} OVERVIEW

5.1 Industrial^{IT} Evolved by Integrating Other ABB Software Suites

As mentioned in the Chapter One, the Industrial^{IT} concept first developed as a common platform to support a growing number of similar products. ABB was able to combine many software products and functionality into its "Aspect Integrator Platform". Those products are displayed in Table 5.1 [15]:

DCI System Six	Freelance 2000
INFI 90	Master
Comtronic	Mod 300
Symphony	Advant OCS
Digimatik	SattLine

Table 5.1 – Partial List of ABB Products Combined Into the Aspect Integrator Platform

Once the AIP concept was developed, other products and services began to map into the platform. Skyva functionality was also later added as a significant part of the Industrial^{IT} vision.

Product	Industrial^{IT} Product
Comp-AC	Drive^{IT} - Low-Power AC Drives
Tru-Mass	Field^{IT} - Coriolis Mass Flow Meters
SIMCONx	Simulate^{IT} - Dynamic Plant Simulator
SolutionsBank	Support^{IT} - Online Customer Services
Isomax	Protect^{IT} - Low Voltage Circuit Breakers
Flexpicker	Robotics^{IT} - Flexible Pick and Place Systems
Azipod	Propulsion^{IT} - Modular Podded Propulsion Systems
Unitrol 5000	Drive^{IT} - Medium/High Power Static Excitation System

Solution	Industrial^{IT} Solution
Preciflex CR	Industrial^{IT} for Body Framing
Galaxy	Industrial^{IT} for District Heating
T-MAC	Industrial^{IT} for Terminal Management
Optimax	Industrial^{IT} for Power Plant Operations
FAME	Industrial^{IT} for Facility Management Engineering

ABB has defined a finite set of product family folders which themselves can contain any number of Industrial^{IT} related products. This was done to clarify obscure "fantasy" names and to promote the cross selling of products. Table 5.1 shows a few examples of product family suite names.

Suite Name	Typical Functionality	Product Examples
Control^{IT}	Control and management of operational variables	OCS components, controllers, PLC's, RTU's, Sequence Control, etc.
Design^{IT}	Tools for design of primary equipment, process trains, or plants.	Process and plant design software or services and consulting for same.
Drive^{IT}	Technologies to supply and improve efficiency of motion, torque, or position	Drives Motors
Engineer^{IT}	Configuration or final design of production or automation systems	Control Builders, Graphics Builders, Documentation, P&ID Diagrams, Layouts, Wire Diagrams
Field^{IT}	Devices or software for process-related measurement or actuation, eg pressure, temperature, level, flow	Transmitters, flowmeters, field positioners and actuators
Measure^{IT}	Misc. measurement devices not suited to Field IT due to industry terminology. Overlaps with Field IT	Force and torque measurement, proximity, voltage, current, stress, paper scanners and sensors.
Simulate^{IT}	Dynamic simulation of automation strategies, productive systems, or business processes.	Simulation software for OCS, Robot Studio 3D, Process modeling, Business Modeling

Table 5.2 – Product Suite Examples

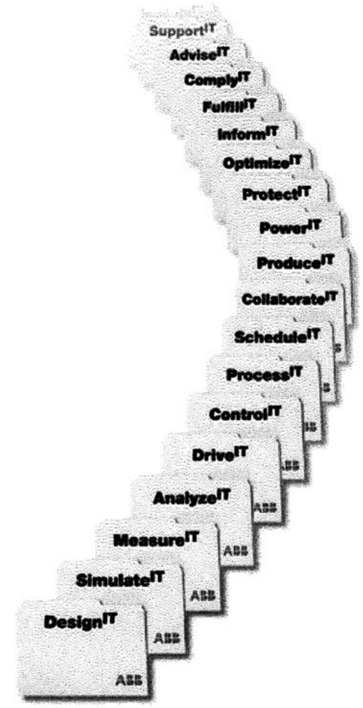

Figure 5.1 – Defined Industrial^{IT} Product Folders

5.2 The Aspect Object Model Combines All Product Information in One Place

ABB's Aspect Object Model provides the means to organize and display virtual objects that represent any number of objects in real life. You can model machines, WIP, users, documents, and all sorts of objects as these virtual Aspect Objects. They are used for interaction with the user and other objects and serve as a placeholder, or container, for all other information or functionality. Every Aspect Object stores only its globally unique identity (GUID) number. Any other facet of the Aspect Object is stored as an Aspect. Even the name of the object is stored as a Name Aspect so that an object is free to have multiple names or share a name with other objects.

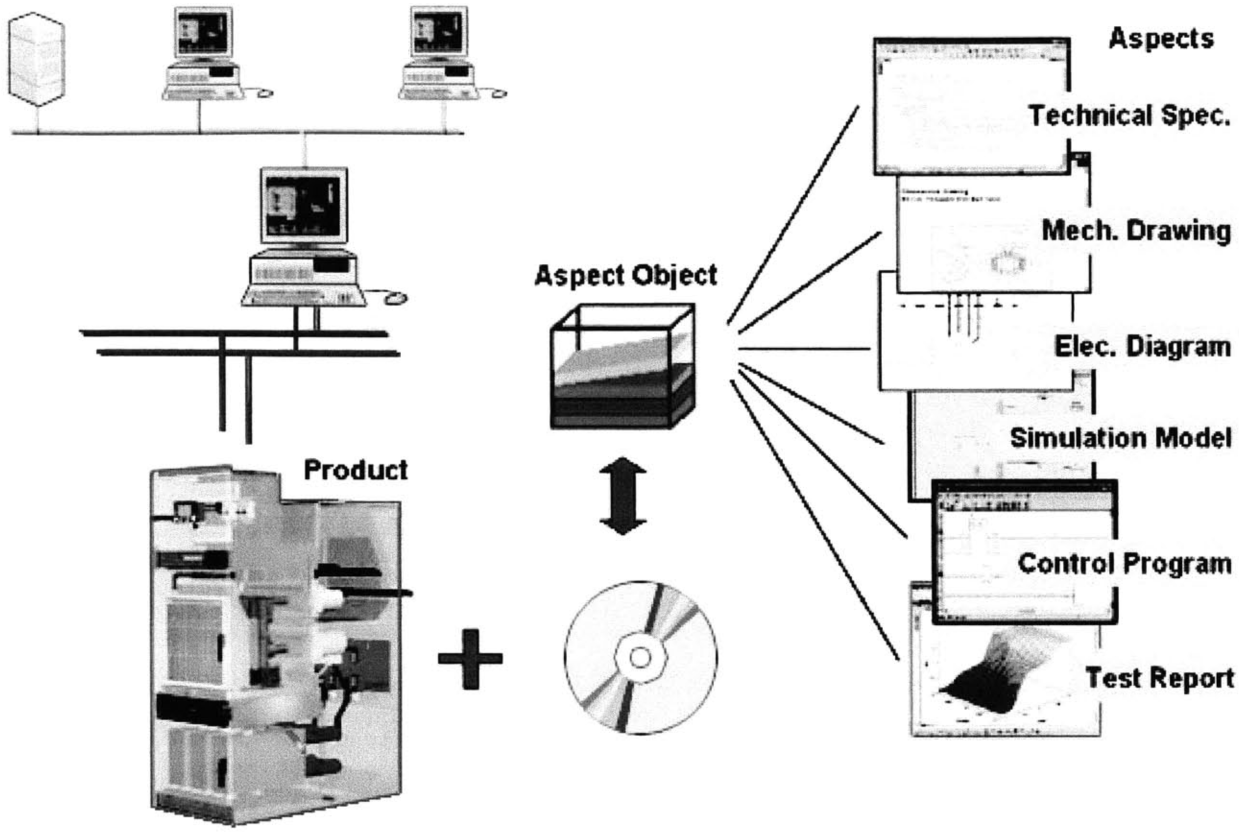

Figure 5.2 – Virtual Representation of the Aspect Object Model

A problem with modern computing systems is that information about real objects is scattered across many applications. A switchgear (above), for example, may have a CAD drawing in AutoCAD, a technical specification in Word, and test reports in MatLab. In this Aspect Object Model, Aspects can be made "aware" of each other to allow for changes in one Aspect to propagate automatically other Aspects.

All of ABB's products in the future will be sold with their Aspect Objects (on CD or for download) containing all of the products' relevant data. If the customer has an Industrial^{IT} system installed at their site, the ABB product can be quickly integrated into the system. This functionality is called Plug-n-Produce [20]. It is much like selling a printer with a CD containing printer drivers to talk to your computer.

In addition to the real time data held in Aspects and organized into Aspect Objects, new functionality can be introduced into the platform by adding software components that interact with those Objects. These software components are called Aspect Systems. In this research, this is how Industrial^{IT} can be extended to work in a discrete manufacturing environment at the Execution and Asset Management level.

As an example, say we place barcodes on WIP and want to add some functionality that tracks those component movements between workstations. A possible implementation is an ActiveX control built in Visual Basic with a simple text field. This can be wrapped into an Aspect System by using an ABB proprietary tool called Aspect Express. Then, the barcode Aspect can be added to the workstation Object so that virtual parts with serial numbers read into the text field will be moved to the that workstation.

```
Dim m_System as ABBSystem          '/Used as a link to a named AIP system
Dim m_Systems as New ABBSystems '/Collection of all AIP systems running on the server
Dim m_Objects as ABBObjects        '/Collection of many Aspect Objects
Dim m_Object as ABB Object          '/Can be set to one Aspect Object

Private Sub UserControl_Initialize( )
        Set m_System = m_Systems("Factory System") '/Connect the ActiveX to the AIP system "Factory System"
End Sub

Private txtBarcode_KeyPress(KeyAscii as String)
        '/The last character of every barcode is the Enter key, which can be detected by the ASCII code #13
        '/When the Enter key is detected, send the entire barcode entry to a subroutine
        If KeyAscii = 13 Then Call MoveObject(txtBarcode.Text)
End Sub

Private Sub MoveObject(SerialNo as String)
        '/Search the Name server for all Objects whose Name matches the barcode
        Dim Sc As New ABBStructureCursor  '/This is a pointer representing a particular location in a structure
        Sc.System = m_System                '/Binds the structure cursor to the AIP system of interest
        Set m_Objects = m_System.Objects("{Name}" & SerialNo)        '/A collection of all objects named SerialNo
        For Each m_Object in m_Objects     '/Loop thru the collection of objects (should only be one)
                Sc.SetCursor newLocation, "Location Structure"          '/Point to the workstation - has to be defined!
                Sc.InsertChildObject m_Object, 0                          '/Insert the object at the new location
                Sc.SetCursor oldLocation, "Location Structure"          '/Point to the old location - must be defined
                m_Object.DeleteAspect ("Location Structure")           '/Eliminate old Location Structure aspect
        Next m_Object
End Sub

Private Sub UserControl_Terminate( )'/Unloading the collections and system object in the reverse order are CRITICAL to
        Set m_Objects = Nothing   '/the prevention of system crashes. This is often overlooked, and can cause random
        Set m_Systems = Nothing   '/problems that are difficult to debug.
        Set m_System = Nothing
End Sub
```

Note that in the MoveObject subroutine, you would have to add your own mechanisms for determining the values of *oldLocation* and *newLocation*. When an object exists in multiple places within the same structure, the DeleteAspect method seems to remove the oldest first. This is not documented, and would not work if you had to be selective about which Aspect to delete, so use carefully. There exists a MoveNode method of the structure cursor, but it does not seem successfully implemented for AIP v1.0.

In order to have access to ABB system objects, you must also add the Reference "Aspect Automation 1.0 Type Library" to the Visual Basic project. In this manner, the Industrial^{IT} system can be manipulated from outside executables, from ActiveX controls or from within standard AIP aspects such as Graphical Displays.

5.3 Structures Provide Intelligent Navigation Capabilities

Creating virtual Aspect Objects for all relevant physical objects in a plant is only half the challenge. The AIP platform is also responsible for organizing the Aspect Objects in a logical manner. This is accomplished by defining parent-child relationships between Aspect Objects in defined Structures, similar to the file-directory structure of a hard disk.

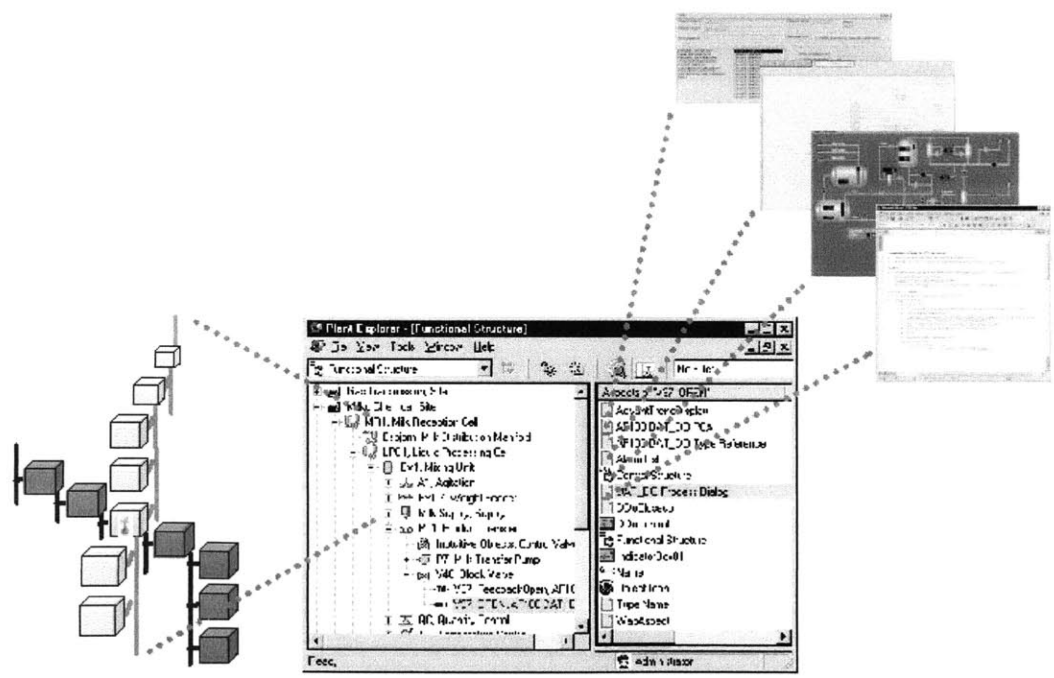

Figure 5.3 - Parent-Child Relationship of Aspect Objects

A key difference to a hard disk analogy is that the organization of Aspect Objects might be done in several structures simultaneously. This allows for the arrangement of objects to be user dependent. For example, consider the proper placement of a casting machine Aspect Object called "Milicron 3". One might create a facility object called "Site" with areas "Front Office", "Production", "Quality", "Warranty", and "Shipping" as children. The "Production" area parent might have departments "Component Assembly", "Casting", "Cooling", and "Finishing" as children. A child of the "Casting" department might be the "Milicron3" object. In this case, the organization is: "Site" → "Production" → "Casting" → "Milicron 3".

This makes perfect logical sense for a process engineer who can think step by step through the function of each department to locate that machine. However, this arrangement does little good for a maintenance worker who may benefit more by having the same machine organized by: "Site" → "Building 12" → "Department 4A" → "Room #3" → "Milicron 3".

Because different users may have different needs, the platform allows for Aspect Objects to be arranged in Functional Structures, Location Structures, Product Structures, Control Structures, etc. In fact, any number of custom Structures may be created to help organize plant objects.

5.4 System Architecture Spans From Device Level to Full Supply Chain

The Aspect Express (for Visual Basic components) and Aspect Studio (for C++) programs register Aspect Systems into the platform framework as COM objects. This way, the Aspect Systems can publish their interfaces with other Aspect Systems allowing for dynamic extensibility of the Industrial^{IT} system.

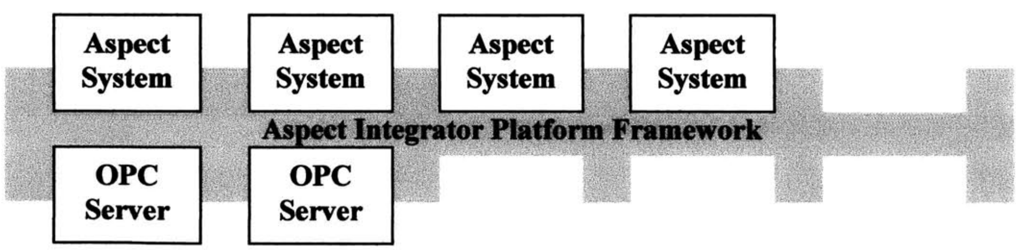

Figure 5.4 – Representation of the Basic AIP Framework

These Aspect Systems along the top may contain home-grown functionalities, such as the barcode example earlier, or they may connect the platform to some private functionality in an outside application. For example, an Aspect System could wrap an AutoCAD viewer (such as VoloViewer) that provides panning, zooming and red-line editing capabilities to drawing Aspects. This extensibility is a key advantage to the AIP architecture because the platform is not one monolithic business solution that must be tailored by expensive consultants or introduces rigidity to the business. Key features can be selected, added, removed and shared at any point in time and as needed.

Along the bottom, connectivity components such as OPC servers are used to query data from the shop floor in real time. A number of standard components are provided with the platform, such as Historian and Trend tools, which can be used from simple monitoring of a temperature gauge to the control of a complete robotic welding cell. Again, the framework layer in-between provides maximum flexibility in connecting a wide variety of applications and plant equipment.

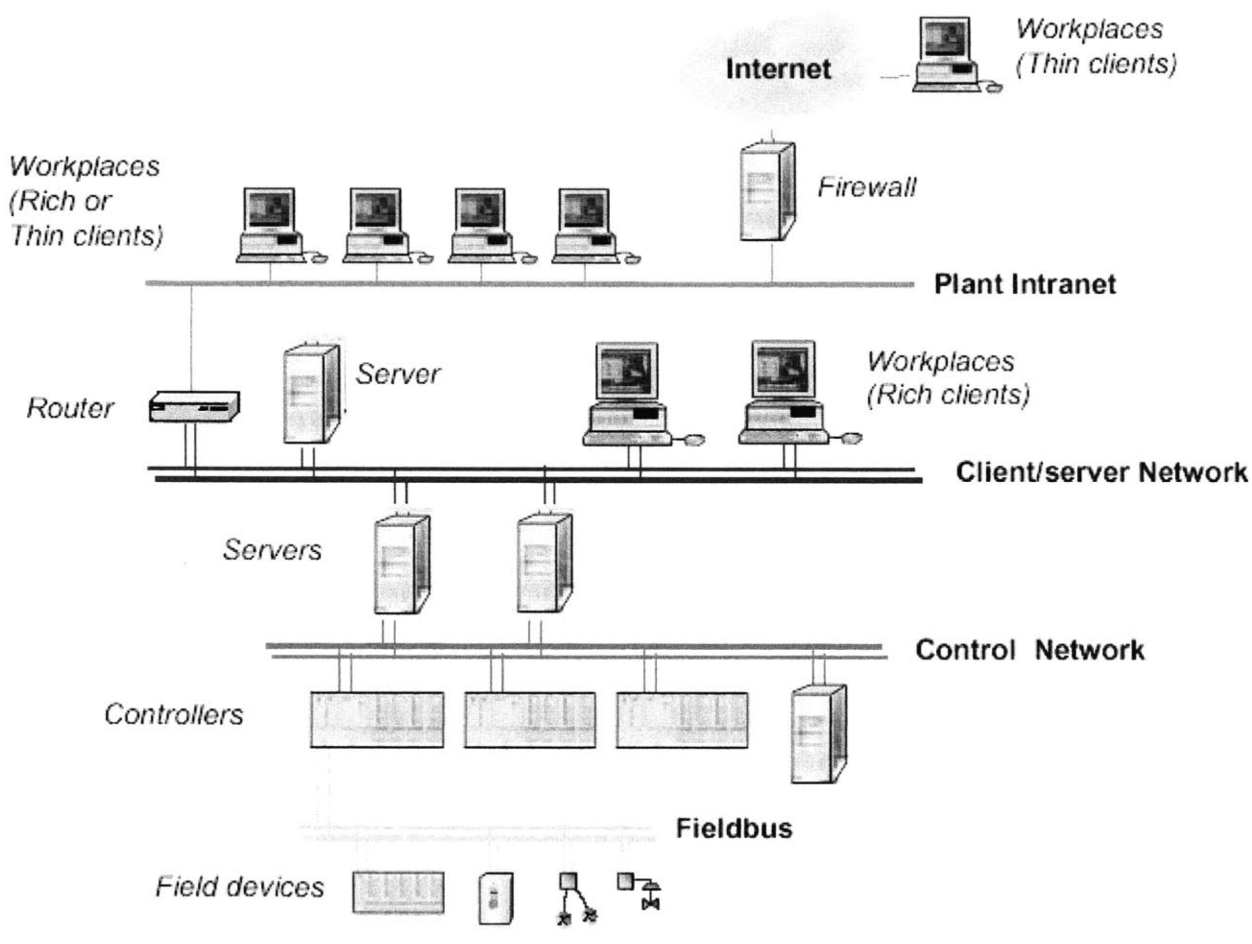

Figure 5.5 - Full Industrial^{IT} Topology

The Industrial^{IT} topology shown in Figure 5.5 shows how real time data from the shop floor is integrated into the Aspect Integrator Platform and shared across the enterprise. Skyva solutions are used for deep modeling of the supply chain [3]. Because the technology is based upon Java, the model can span across many factory sites via the Internet. Plant status can be sent to a Skyva *Agent* to aid in planning and scheduling. The agents can return order information back to AIP [28]. ABB is also developing Thin Client support for AIP so that information can be retrieved by cell phone or Personal Digital Assistant. Back on the shop floor, connectivity components can be built to poll values from the Fieldbus or Control networks. These are arranged in Aspect Object Model stored on the Client/Server network. In this way, one machine may send information to many Workplaces, or a single Workplace may control several machines. This is a departure from a more traditional approach to integration.

5.5 System Design Promotes Scalability and Flexibility

A large market exists for third party system integrators to connect legacy systems together. By employing various technologies, they are able to unite different hardware systems (ex: BACnet, LonWorks), different software systems (ex: OLE, ActiveX) and hardware to software systems (ex: OPC). The unfortunate consequence to this is that such systems are not easily scaled if the company is growing. A system must remain flexible because companies often cannot anticipate their future IT needs [23].

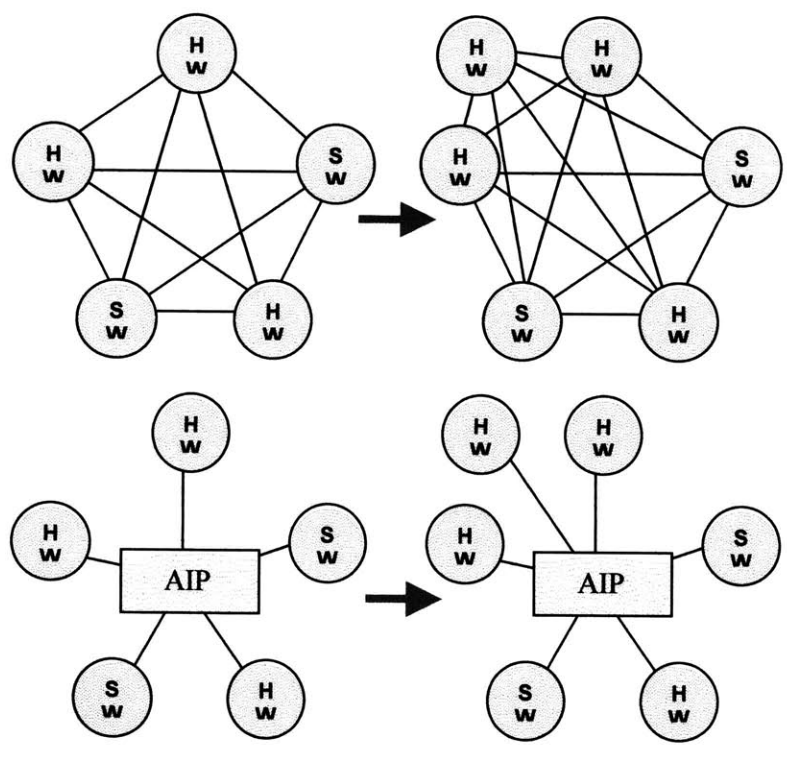

Figure 5.6 – System Integration Model in a Growth Environment

As shown in Figure 5.6, the Aspect Integrator Platform can be used as an interface layer between hardware and software. In this manner, additional equipment or software functionalities can be added by providing a single extra link to the platform, instead of through many links to other pieces.

One ABB manufacturing and assembly plant studied in this research that manufactures "sub-components" is a highly automated and integrated facility facing a growth rate of nearly 20%. Most departments are integrated into the SAP system. Local databases store sub-component product information, such as the process measurements made in the blast furnaces. Some machine controllers are also connected, such as a system for downloading NC path programs. Some hardware, such as the cleaning lines, can be monitored from the front office by a plant view application.

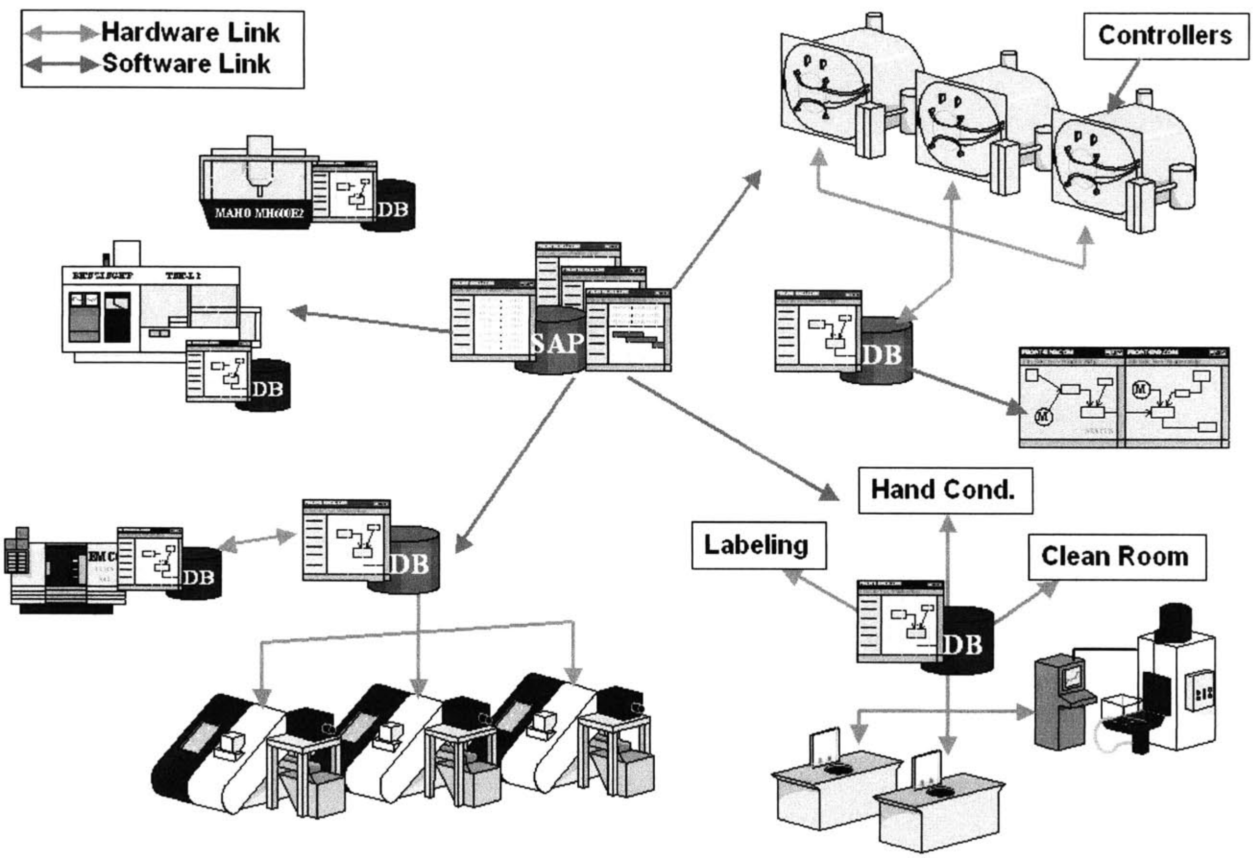

Figure 5.7 – Hardware and Software Links in an Integrated Manufacturing and Assembly Plant

Engineering is currently working on a homegrown quality tracking system that will store data on an SQL server. The challenge is to connect the server to the same machines that are already connected for monitoring, order handling and controlling. Further, information about these manufactured sub-components would be useful in the main "component" Business Area Unit, where 90% of these sub-components are delivered.

If this business were to combine all of its hardware and software onto an Industrial^{IT} system, adding new applications or expanding the equipment on the shop floor could be handled directly via the AIP platform.

Additionally, all information about a particular sub-component could be found in one place. The main component facility is located adjacent to the sub-component facility, so they could also link to the AIP platform and share certain information. It was found, for example, that the sub-component business would hold off on making parts until the casting machines in the main component area were ready in order to keep inventory levels down. The component business, in turn, would hold off setting up casting machines until sub-components were available to keep their capacity utilization high. A great need for coordinated scheduling exists.

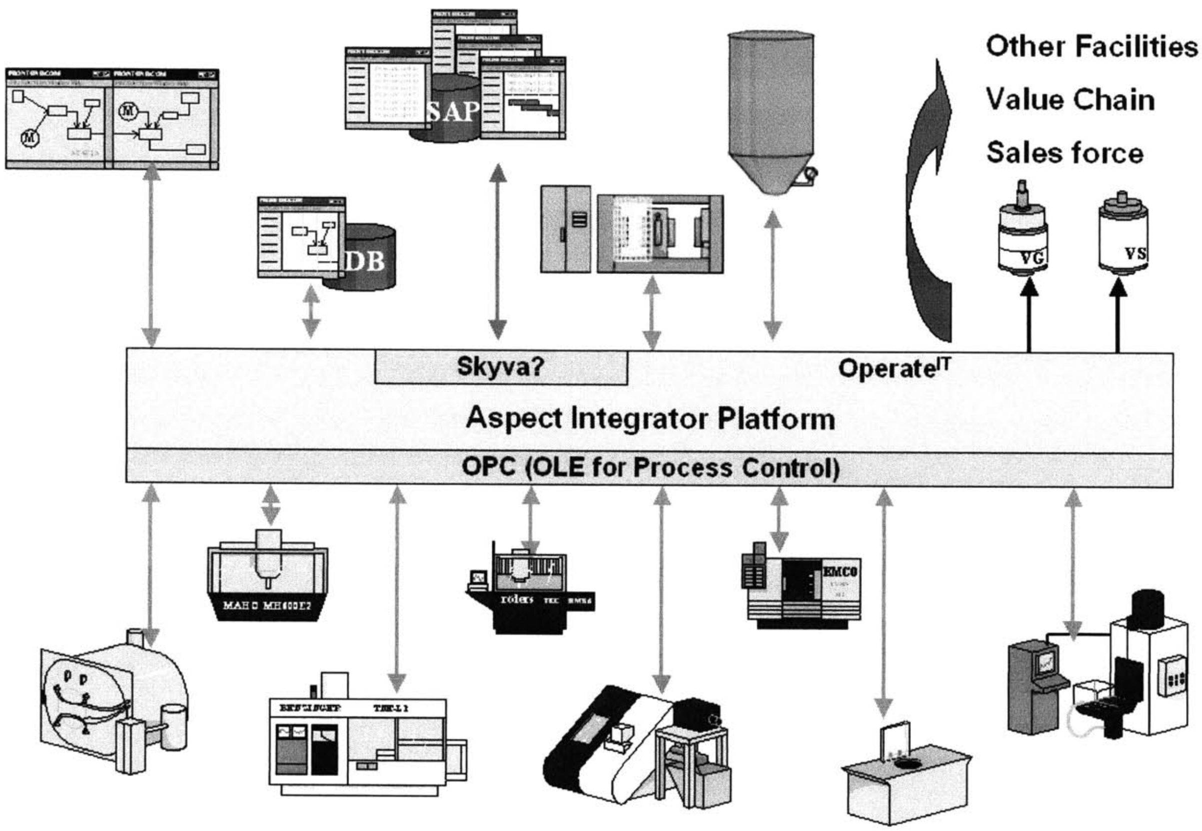

Figure 5.8 – Industrial^{IT} Links in an Integrated Manufacturing and Assembly Plant

5.6 Industrial^{IT} Functionality Extended by skyva

As mentioned, ABB's complete Industrial^{IT} vision includes two major pieces. The first is the Aspect Integrator Platform that has been discussed so far in this chapter. Additionally, ABB has also a major investment in Skyva International. Skyva technology extends Industrial^{IT} by giving the user the ability to deep model an entire supply chain (or any piece thereof) as a state machine on top of an IBM's San Francisco database. Based upon the Java programming language, powerful Agents can be developed to provide decision-making capabilities over great distances by using the Internet.

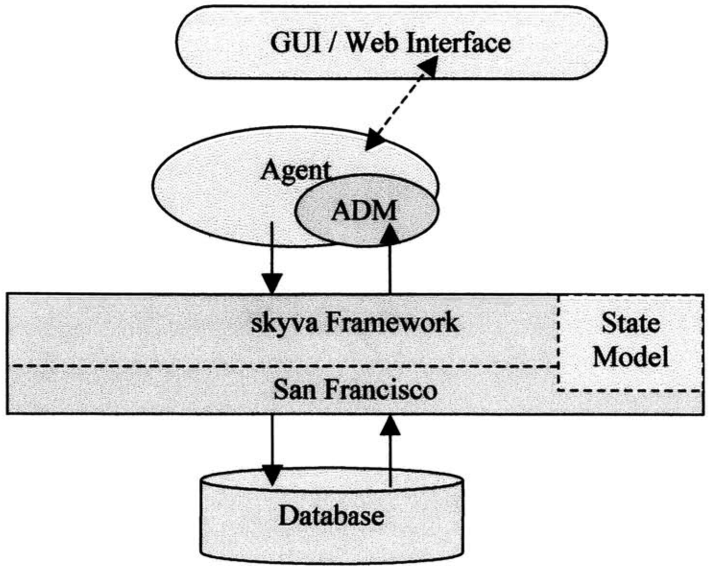

Figure 5.9 – skyva Agent Structural Relationship [29]

The skyva advanced planning and scheduling algorithms utilize hybrid models based on several types of modeling. This is because of inherent problems with using any of the methods of modeling solely. Mathematical modeling, for instance, is often limited in terms of robustness and scalability to handle a wide variety of real life problems in industry. Heuristic models are often too prescriptive and are difficult to maintain under changing conditions. Constraint satisfaction becomes increasingly complex when used for large supply chain modeling, which can cause backtrack explosions. Stochastic searching is computationally intensive with little guarantee for optimality. Multi-agent modeling can only be done for simplified problems, reducing its effectiveness. The skyva strategy is therefore to build constraint satisfaction models, but to utilize mathematical, stochastic and heuristic algorithms to avoid or handle backtrack problems [29].

This makes skyva particularly suitable for Business-To-Business (B_2B) integration, and it has also been shown to provide excellent links to SAP and other ERP systems. Skyva is useful for synchronizing manufacturing and business systems together, providing integration with suppliers, automating processes, and for providing logistics for Collaborative software. Table 5.2, taken from an ARC report, shows how the skyva – AIP coupling fulfills ABB's requirements for a complete collaborative e-Manufacturing strategy [3]. Note that due to time constraints and the lack of accessibility to the skyva technology from the FICRC center in Finland, only the Aspect Integrator Platform technologies were used in the developments shown in Chapter 6.

Capability	AIP	Skyva	Industrial^{IT}
Synchronize Manufacturing with Business Systems	√	√	√√√
Outsourcing and Supplier Integration		√	√√
Automate Business Processes		√	√√
Generate Value by Empowering People	√		√√√
Integrate Engineering with Plant Floor	√		√√
Logistics CRM plus SFA integration		√	√√
Enable Collaborative Maintenance and Support	√		√√√

Table 5.3 – e-Manufacturing Capabilities Utilizing the Aspect Integrator Platform and skyva

5.7 Chapter Summary

Industrial^{IT} was developed to integrate many existing ABB applications and products. As such, it is well suited for the integration of other types of non-ABB software and hardware as well. It can accomplish this via a fully expandable series of Aspect Systems for software and Connectivity Components for hardware. The AIP platform can also be easily scaled and modified by building custom Aspect Systems in C++, Java or Visual Basic. With these systems and components in place, any number of real life objects can be modeled as virtual objects within the Aspect Object Model. The Aspect Object Model provides a solitary view of a virtual representation of a real object by combining several Aspects in one place. The Aspect Integrator Platform (AIP) helps to store and organize these Aspect Objects and their Aspects into user-definable Structures. Individual Workplaces can be tailored for each user of the system.

Industrial^{IT} is made of two major components: the Aspect Integrator Platform and skyva technologies. Skyva can be useful for linking manufacturing systems to business systems and other parts of the supply chain, however, the course of this research does not cover skyva functionalities because of time and availability constraints. The next chapter shows the results of several feasibility studies in four of ABB's factories using only the Aspect Integrator Platform technology of Industrial^{IT}.

6.0 SOLUTION EXAMPLES

6.1 Feasibility Studies Evaluated in Four Plants

If Information Systems were a wall, the AIP platform would be analogous to the mortar. The purpose of mortar is to hold bricks together and to fill in the gaps. This is to say that a complete solution (Figure 6.1) can be built upon many existing external software "bricks" (ex: SAP master schedule, existing SQL database used in QA) held together by AIP, as well as being built with functionalities in the AIP platform itself (ex: Paperless operator panel, Integrated test reports).

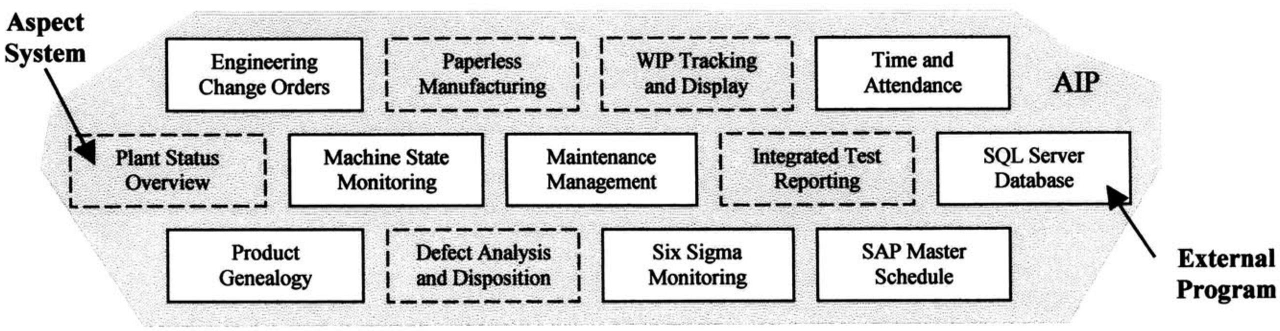

Figure 6.1 – Analogy of Building a Wall Versus a Plant Solution

This represents a far different approach to integration of business systems than done for ERP systems. Traditionally, existing systems are torn out and replaced by modules in the ERP package. Therefore, an ERP package tries to implement an entirely new wall. With Industrial^{IT}, the existing systems can be built around or replaced at the owner's choice. Further, the implementation can be done in progressive stages, which significantly reduces risk. For example, a plant may choose to install a WIP Tracking function. Once that is in place and they are comfortable with it, they can add an Operator Panel that uses the WIP tracking function to tell the user what work is waiting at their station. Finally, the Aspect Systems (AIP "bricks") can be easily Exported and shared with other users. Therefore, if one ABB plant comes up with a clever system for handling preventative maintenance, this system can be shared by hundreds of other plants over email at no cost.

During the course of this research, several Business Area Units (BAUs) were evaluated for potential Industrial^{IT} solutions. This chapter gives a series of examples of solutions that were built upon ABB's AIP platform to handle Execution and Asset Management style activities. Although these examples are shown individually, they might be used in conjunction with each other, or other software, as part of a larger EAM strategy. Note: Some figures are marked to protect the identity of individual plants or parts.

The first BAU studied was a component factory in Scandinavia. This company was selected for three main reasons:

1. Small number of details: The products had very few main subcomponents: wound core, epoxy, wiring harness. The manufacturing processing steps were also limited: component fabrication, casting, cooling, testing, final assembly.

Low complexity => Faster understanding and deployment capabilities.

2. Large potential for impact: Quality yield on main process is roughly 50%, large amounts of non-value added information handling, and high pressure for corporate to improve protits.

Maximum impact => Greater management buy-in.

3. Convenience: New equipment with ability to interface with Industrial^{IT} had been purchased but not used in production, there did exist initiatives to improve product and processing, and the factory has had close cooperation with FICRC in the past.

Convenient access to resources => Better opportunities to test out new technologies.

After promising initial results in Scandinavia, the Power Technologies Division asked to move the research to a site in Germany. This facility is host to three other BAUs studied during this internship: a "sub-component" plant, a "component" plant and a "final product" plant. This site was selected for entirely different reasons:

1. High performance site: The growth rates in the BAUs are between 10-20% per year, and space is at a premium. The facility was recently constructed, but there is little room for expansion.

High growth => Productivity and capacity improvements needed to offset expansion

2. Highly integrated operations: Nearly 90% of the sub-component output goes to the component BAU. More than 75% of components are sold to the final product BAU.

Integrated businesses => Synergies exist in shared data, planning and lead time reduction

Each of the following sections will discuss a problem faced by a particular plant, some causes of the problem, related findings in other plants (or outside ABB), and the solution that was created to solve the problem.

6.2 Integrated Test Reports Aid Root Cause Analyses

Problem

One category of quality failures that occurs in the Scandinavian plant is Electrical Test failures. The exact causes of the different types of electrical failures are difficult to pin down.

Issues

Performing root-cause analyses to determine the source of these errors is difficult because there are few means to perform correlation studies. It is widely believed that "high voltage" failures are caused by operators who mishandle subcomponent parts as they are loaded into the casting machines. It is also believed that "accuracy" failures are caused by fluctuations in temperature or pressure in the casting machines. However, even when data sheets were introduced to start recording the histories of machines and operators, they are done by hand. This adds direct labor content to the job and requires a significant indirect labor expense for accumulating the data into spreadsheets for analysis.

Related Findings

Interestingly, the epoxy material and processing employed for casting components in the second German BAU is nearly identical, however the quality yield for their "components" is much better. The potential for sharing cause and effect data across ABB is enormous.

This second component plant also has trouble doing root-causes analysis because their parts are not serialized. (Oddly enough, the sub-component parts cast inside them are serialized). Therefore, to accomplish this solution the components would benefit from an inexpensive, passive radio frequency tag that could be detected by the computer system for identification.

Solution

Depending upon the test equipment, many sensors and controllers give off data in OPC format. This can be collected and stored into a General Properties Aspect in real-time through the Control Structure. Data that is not OPC compliant can be also translated into the General Properties Aspect by building a small applet in C++ or Visual Basic with a Reference to the Aspect Object Automation type library.

In this same way, a Word document can populate its form with the data back out of the general properties using VBA script, XML or with custom ActiveX components. Aspect Systems for integrating MS Office documents into the Aspect Integrator Platform already exist. Therefore, the data can be easily gathered, sorted and filtered by the General Properties aspect – and viewed or printed by the person in a familiar Word document format.

Shown in Figure 6.2, a Reject bin is set up as a child of the Casting Department object in the Production area. A defective component in this area lists its Aspects, including a Test Report aspect. A preview of the test report displays data found in the Sensor Properties aspect, but in a form that is exactly the same as its paper equivalent. Additionally, if the test data is outside of the specification limits, the cell will be highlighted in red.

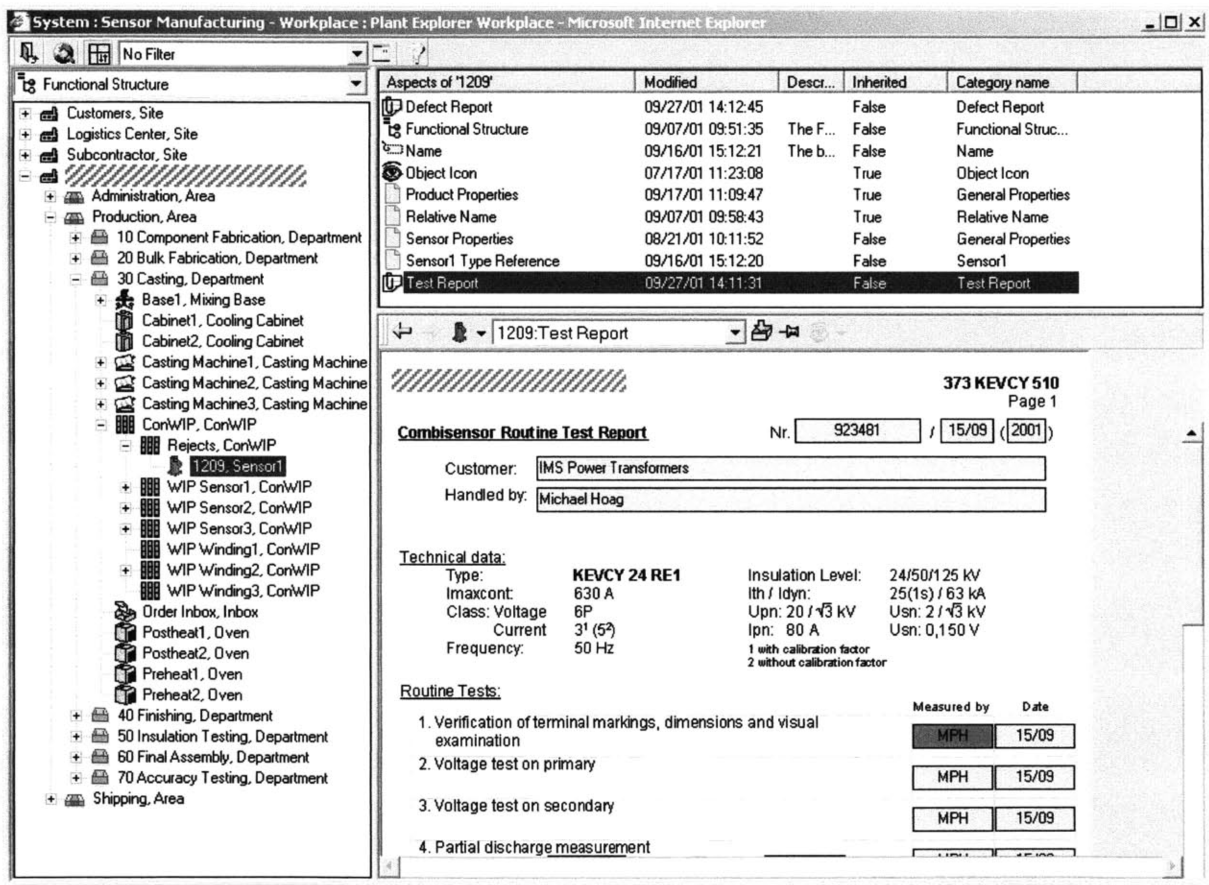

Figure 6.2 – Screenshot of a Test Report Aspect in the Plant Explorer

Key parameters, such as the high voltage measurement, can be plotted over time using the standard Trend and Analysis tools provided with the Aspect Integrator Platform. ABB will extend these functionalities by developing a suite of root cause analysis tools, called Optimize^{IT}. The data could also be harvested into a third party analysis package such as MatLab or Anova to support DOE or Taguchi experiments to determine the source of defective parts.

A closely related Aspect that was developed was the Defect Report aspect in Figure 6.3. This is an ActiveX component built from Visual Basic that was wrapped into AIP using Aspect Express. It uses an MS Access database on the back end for record storage.

Some interesting features on the Defect Information tab include an interactive graphic with 'hot spots' that an engineer could use to click on a defect area. A listing of common defects for that area would appear, along with repair instructions, pictures and / or movie clips, history and defect analyses such as Pareto charts.

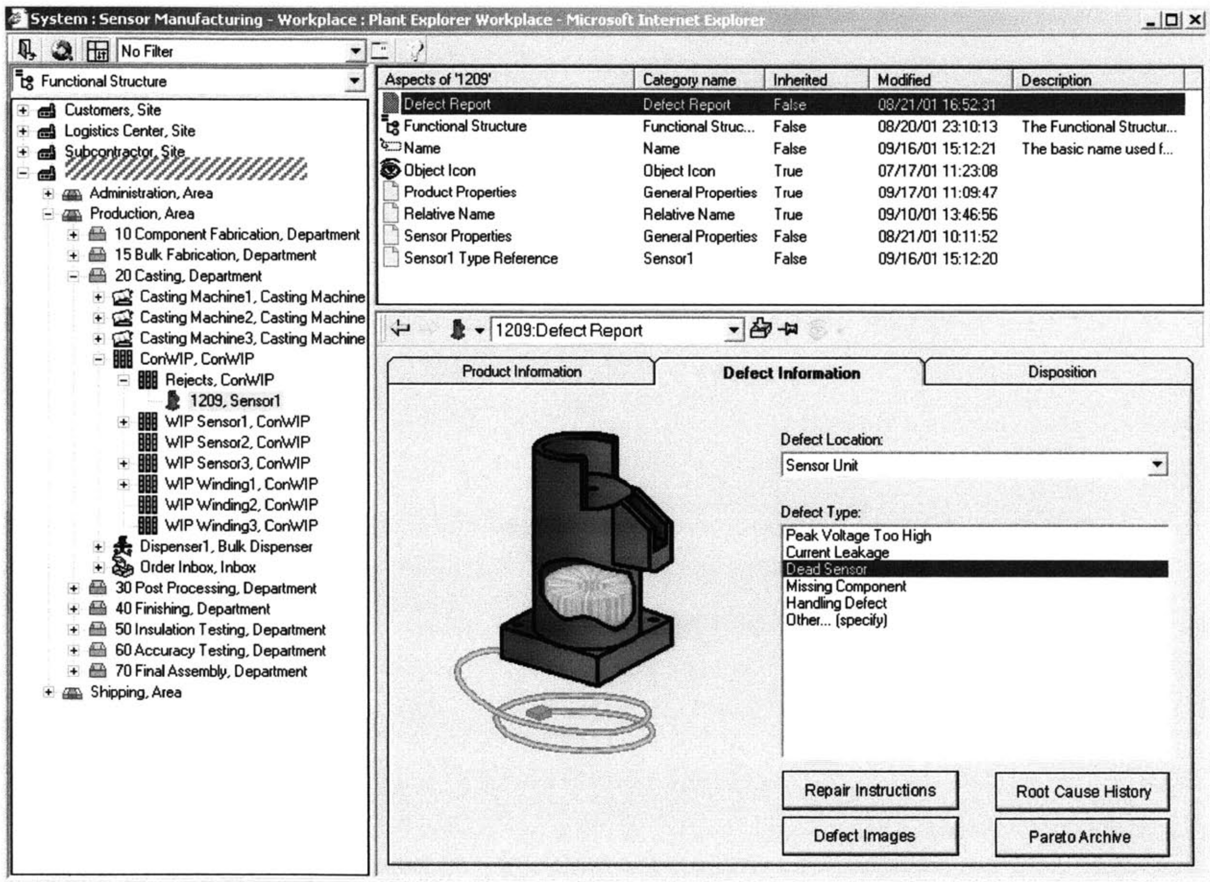

Figure 6.3 – Screenshot of a Defect Report Tool in the Plant Explorer

In most cases, this kind of information exists only in the heads of a production area's manufacturing engineers. When these employees transfer, retire or leave the company much of this background information goes with them. Instead, this database of disposition knowledge can be built up over time as pictures and instructions are created and remain as a permanent record. This greatly decreases the amount of training and learning curve that is necessary to bring new engineers up to speed, and is also valuable feedback to product design engineers in R&D.

The Disposition tab, shown in Figure 6.4, displays information about a particular serial number, including current status and notes (observations, likely causes, instructions). In this factory, a sign-off procedure by engineering and QA is also handled by this Aspect. In an implementation of both 6-sigma and ISO 9000 programs, these types of tools are very useful.

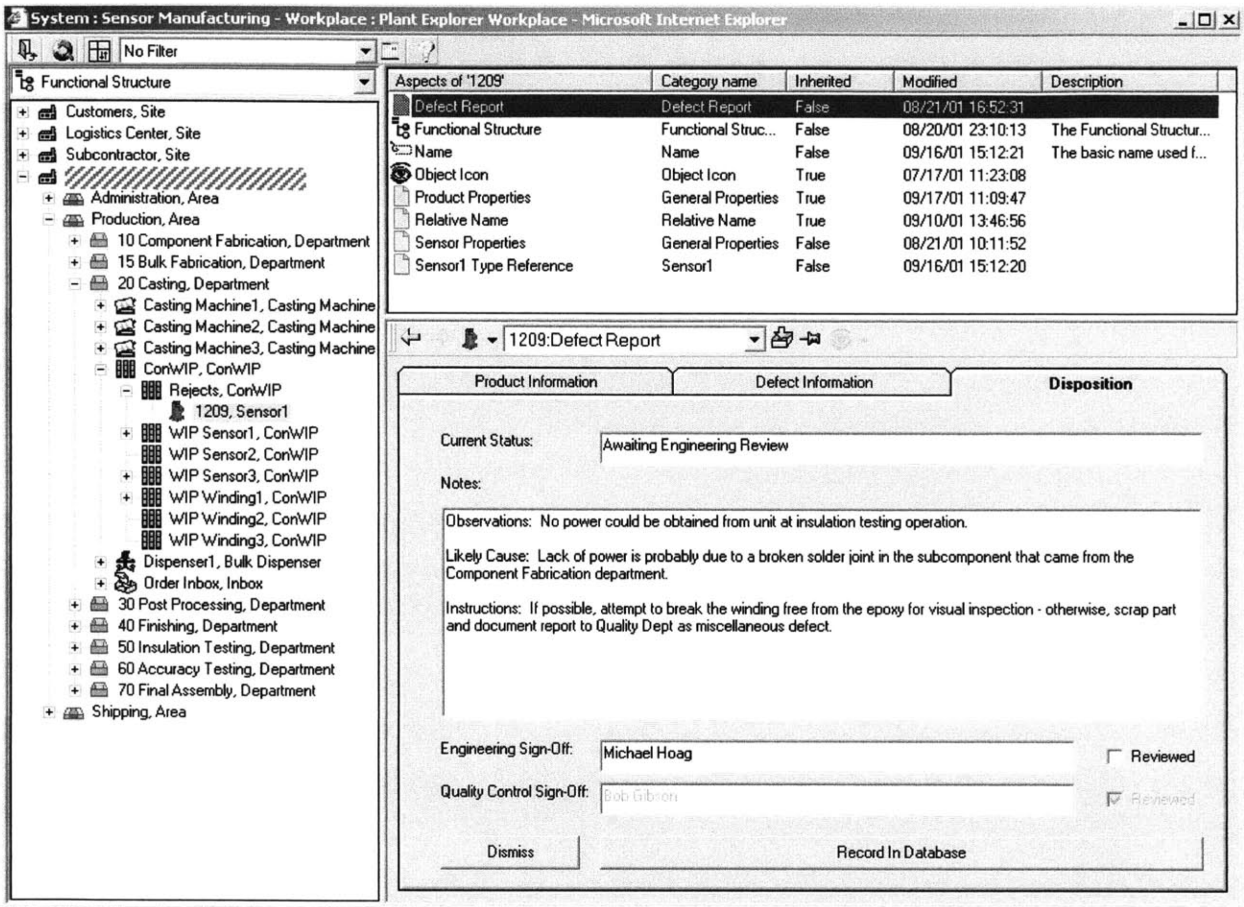

Figure 6.4 – Screenshot of a Defect Report Tool in the Plant Explorer (Part II)

6.3 Custom Assembly Operator Workplaces Help To Improve Productivity

Problem

Unnecessary complexity, unreliability and a poor understanding of the benefits are a few reasons why manufacturing operations are notoriously slow to adopt new computer systems. Often, an integrated IT system attempts to fit all sorts of data on one screen. This can be overwhelming, especially if an assembler has little previous computer experience.

In this example, the viewpoint of an assembly operator at the final product BAU is considered. This task is particularly challenging because the worker must assemble a wide variety of paper documents from many sources to even start the next job. SAP orders come off the printers, special notes and drawings come from engineering, scheduling comes from the supervisor and test reports come from QA. Some workers collect up to 10-15 documents for each final product that needs assembling. This is an ideal environment for developing a paperless manufacturing operation [7].

Issues

The information requirements of individual users may be completely different depending upon the job responsibilities. Depending upon the user, full access to all Structures and Aspect Objects is both unnecessary and potentially hazardous. You would not want to give an operator the opportunity to accidentally delete an entire structure for example. Therefore, the Plant Explorer view is not a good tool for use on the shop floor. Instead, custom tailored Workplace views can be created in the Aspect Integrator Platform allowing access to only the necessary information to complete a particular job.

The reason so many documents are necessary is that ABB produces tens of thousands of variants of final products. This is due to the different power regulations amongst its worldwide base of customers. Therefore, most final products have unique features or test requirements much like that found in a job shop environment.

Additionally, the workforce in this BAU is comprised of nearly 50% temporary contract workers. Training expenses are therefore higher than in other ABB facilities also producing final products. As mentioned earlier, the growth rate in this area is also in double-digits. With little space left for expansion, increasing worker productivity would help prevent the need for expansion.

Related Findings

While not a BAU studied in this project, there is an ABB facility in Virginia that created an impressive integrated enterprise solution using only MS FoxPro. The system's developers were very proud that every user had the exact same view of the data, from sales to engineering to manufacturing. However, this is not the most efficient arrangement because only a small amount of the data is shared from any given function with another one. Similarly, the plant in Scandinavia assumes that the only way to implement Baan in their factory is to train *every* employee in the company on how to use it.

Solution

Using ABB's Graphic Builder, an extension to Visual Basic, the requirements for the assembly of a final product were studied. The Assembly Operator Workplace, shown in Figure 6.5, contains basic information useful to a newly hired contract worker. For example, the three partially assembled final products at the workstation are listed at the left. By clicking on one, a stock list with a diagram showing where to find the components at the station, any special instructions and even a picture are displayed.

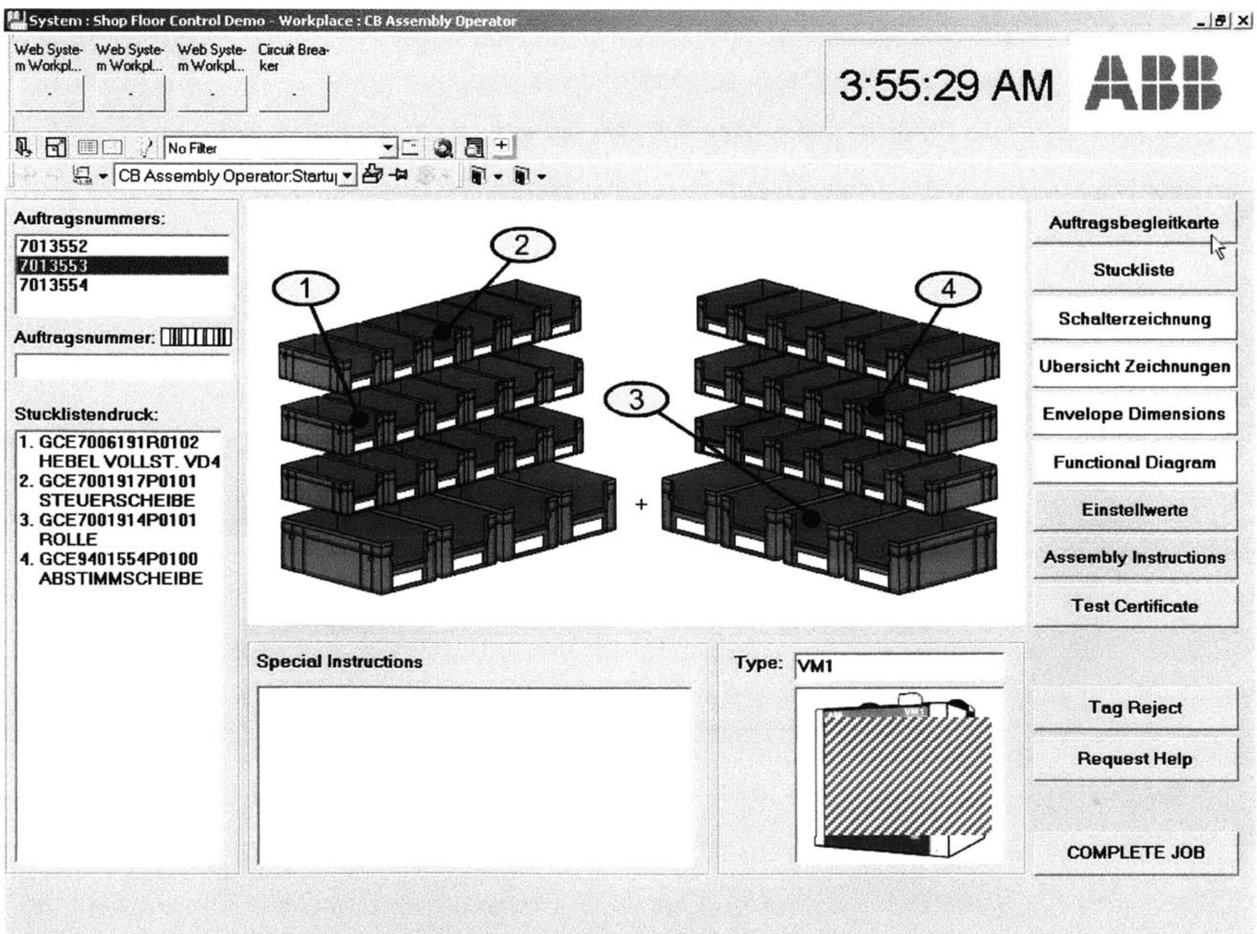

Figure 6.5 – Screenshot of an Assembly Operator Workplace

Down the right hand side, links to important documents such as the SAP work orders (as flat text files), engineering drawings, assembly instructions and test certificates are displayed. The productivity of the user can be improved by allowing them to stay at the work center for longer periods of time. Efficiencies can also be gained because errors due to document revision can be eliminated, the operator can request help from maintenance or supervisors directly from the computer and they can get real time feedback about their personal defect rates.

If radio frequency tags or barcodes were placed on the products, these documents could be loaded to the screen automatically or by a scanner. The flow of products into and out of the work centers can also be used to estimate productivity between different workers, shifts and departments unobtrusively. In the future, the component diagram might be linked to a "pick-to-light" system like that deployed in Dell's kitting area where each bin lights a LED to help navigate the user to the parts.

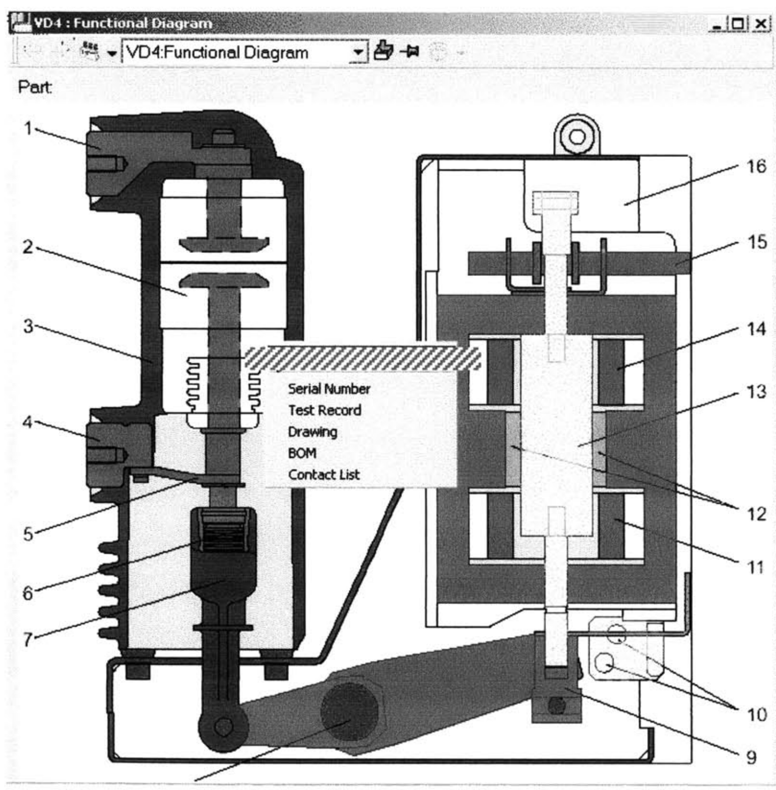

Figure 6.6 – Screenshot of a Functional Diagram for a Final Product

Without Structures, the assembly operator has no means to navigate to other types of information however. For example, if the worker is having difficulty with a subcomponent, they would benefit from checking the serial number, seeing a drawing or having a contact list of people to call for assistance. To allow for this kind of navigation, a Functional Diagram aspect was created and placed in the right hand column. This aspect appears as a cross sectional view of the final product, as shown in Figure 6.6.

By hovering over 'hot spots' on the Functional Diagram, context based navigational support is available. Figure 6.7 shows a list of available information about the sub-component simply by right clicking on it. A full listing of all the final product's aspects can be found in a drop down menu at the top of the form.

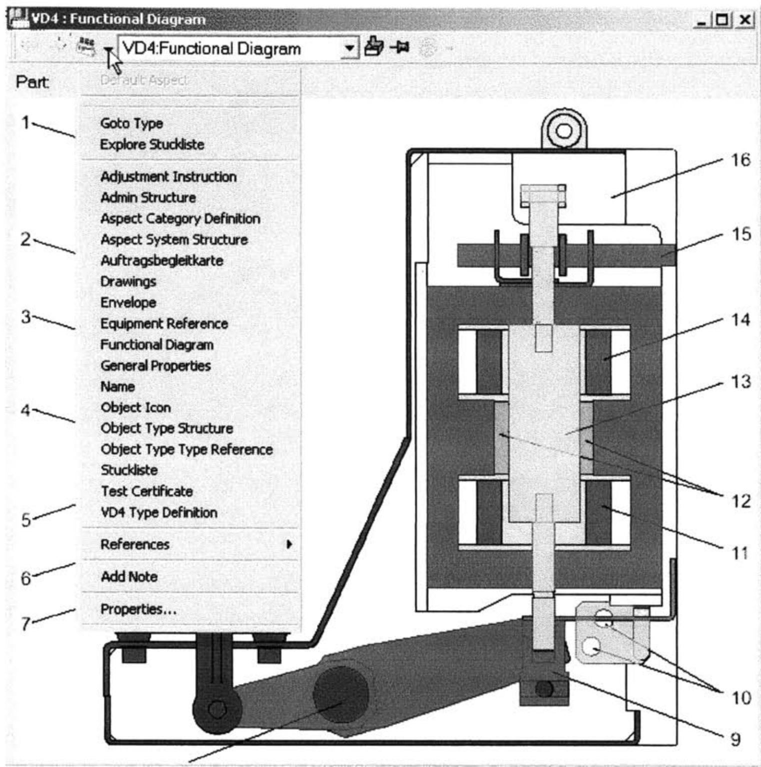

Figure 6.7 – Screenshot of a Final Product's Aspect Listing

Developments such as these are promising steps towards achieving paperless manufacturing. Experience on this project shows that users are more comfortable using the system if they:

1. Assist in designing their own layout
2. Are shown information in a format that looks familiar (ie: the view is the same on paper)
3. Are not required to expend extra effort to pull up information on a computer

The plant determined that a 5-10% bump in capacity would be possible by implementing this solution. This meant that the Workplace aspect would payback its cost of development it in only two months. (The cost of licensing AIP and the purchase and installation of the computer infrastructure is not included in this figure, but this is significantly less than the labor required to deploy the solution).

6.4 Plant Overview Helps Identify Production Delays and WIP Levels

Problem

Production problems and delays can be difficult to detect quickly on a factory wide level. In this example, a WIP overview was developed to provide a manager with the ability to quickly glance at the department loadings for a few major product lines. This was done for the plant in Scandinavia.

Issues

Currently, a physical inventory count is done once per week to determine the positioning of WIP in the factory. This is accomplished by hand, taking several hours. Results are plotted week by week in the plant manager's office. In this factory, one cannot quickly visually examine the shop floor to find bottlenecks because the flow through the plant is not organized in a linear fashion. (Because of the large electrical test equipment and heavy casting machines, reorganizing the shop floor is difficult. Another FICRC research team is investigating an optimized process layout concurrently with this research).

When a customer calls to find out the status of an order, the order number listed on a paper production traveler has to be found by hand. It is similarly difficult for the parts suppliers to know when to deliver new parts. Many of the parts are supplied by an ABB owned Logistics Center located close to the factory.

Related Findings

A similar situation is found at the final product plant in Germany. While SAP could be used to determine approximate positioning of WIP, accurate inventory levels were difficult to keep in sync. They also have the problem that nearly 40% of the products do not make it down the line on the first pass and had to go back for adjustments. This level of re-entrant flow is not easily tracked in traditional ERP systems. Plants that use MES systems to track WIP in real-time instead of ERP are, on average, able to reduce inventory levels by 45% [8].

Solution

A Location Structure for each plant was created to store information about the arrangement of machines in the department, and departments in the factory. A ConWIP (constant WIP) object for each buffer area served as a parent object for holding the virtual WIP objects at that step. When an operator scans a product's barcode into their workplace (refer to Figure 6.5), or an RF reader detects a radio frequency tag on the product, the Location Structure would be updated to put the product in the correct ConWIP.

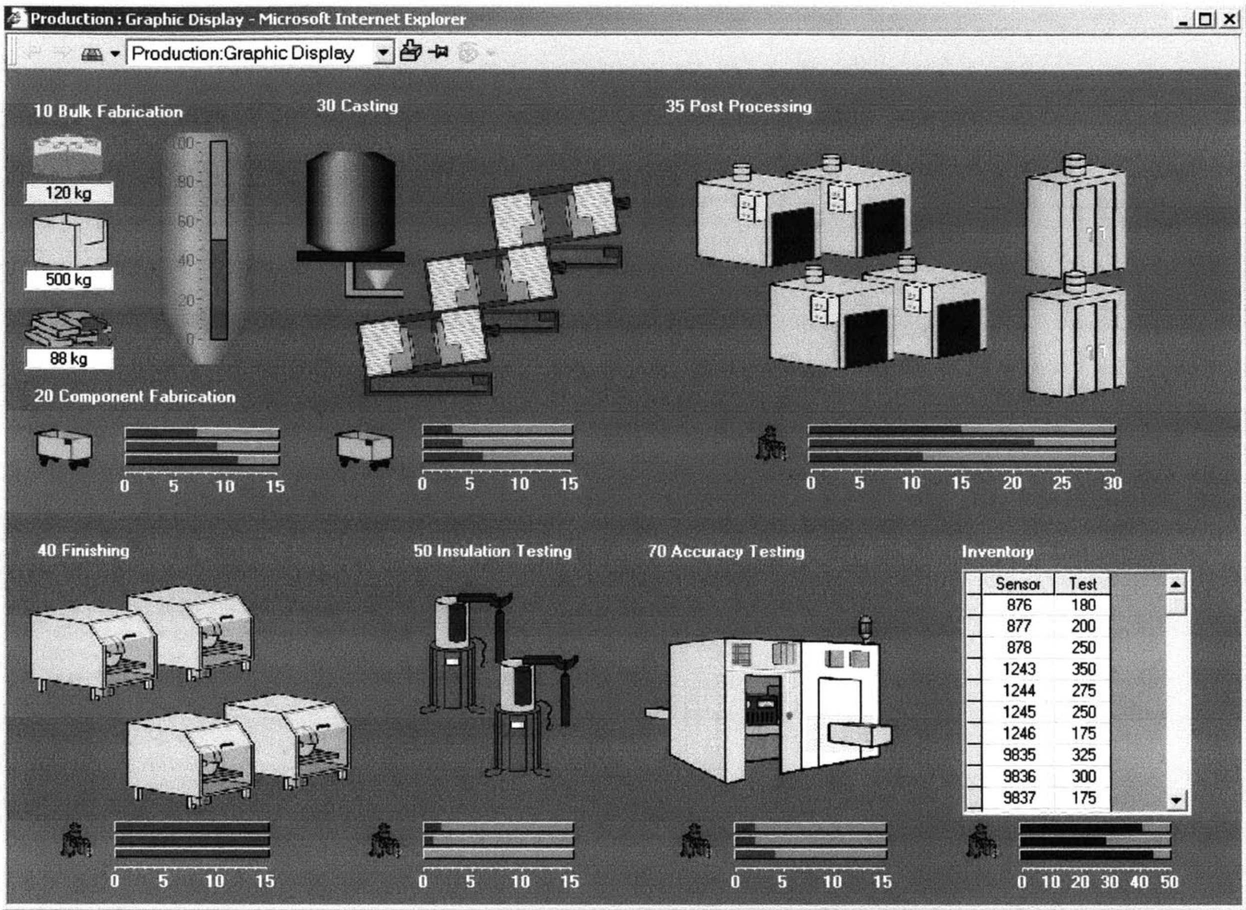

Figure 6.8 – Screenshot of a Plant Overview Display

With a Location Structure full of WIP position data, a screen such as the one shown in Figure 6.8 can be made showing the loading for major product lines in the various departments. With just a quick glance, the production manager can see that the Finishing Department is packed with WIP, but the Insulation Testing Department has only a few pieces to work on. They could then head to the Finishing area to see what might be wrong. Also, the Bulk Fabrication Department is physically located in another BAU, but the manager can see material levels from this screen as well. By using ABB's Graphics Builder, these screens can be made in a matter of minutes with little, if any, coding required.

A similar screen was created for the final product BAU. Here, the final products are transported on an overhead conveyor system. A birds-eye view of the conveyor was used for the background image, and the ConWIP object stored not only the quantity of products at a station, but also the (x,y) position of the buffer on the map. In this way, the WIP's actual position could be seen on the screen as well. The ability to trace WIP is a critical function necessary to move to Make-To-Demand manufacturing [4].

6.5 Department Overview Helps Monitor Shop Floor Activities

Problem

Running a shop floor requires a complex coordination of people, parts and equipment. Much like a plant manager benefits from having increased visibility, a department manager would also benefit from some simple tools to see what is going on. In this example, a department overview screen and related Aspects were developed for the Casting Department of the plant in Scandinavia.

Issues

Scrap from the casting department could be as high as 25-50%. The material used in the casting process is sensitive to changes in temperature and pressure, and to oils in human skin. Also, the shelf life of the mixed components is very short (a few hours). The mixing process in done in another department and the material is stored locally at the casting machine in small tanks. The department manager has to remember when different tanks are filled to make sure the mixed components do not sit for too long.

The department manager is also responsible for ordering new subcomponents, coordinating preventative maintenance and mold cleaning activities, switching machine setup based on incoming orders on some machines (others are dedicated), getting the cast parts directly to the post processing area, and a number of other activities.

Related Findings

In all of the business areas, department managers deal with similar difficulties. In the sub-component BAU, the products are assembled in a single step. The subcomponents are set into racks and placed into large blast furnaces. The oven has to be filled to capacity with only one type of sub-component or the thermal profile is adversely affected. They have only three ovens. Therefore, if a customer orders 150 sub-components of type A and the oven capacity is 250, then the remaining 100 parts have to go into stock and no other types of orders can come from that oven. They could not utilize SAP to coordinate the schedule, so it is done by hand. An Aspect System was created to help optimize this step.

In the component BAU, the manager has to produce hundreds of product variants on only eight casting machines. Setup times are lengthy and last minute shortages of interrupters or other components have significant impact on capacity. Again, the SAP system could not handle rapid changes on the shop floor so this scheduling is also currently done by hand.

As mentioned earlier, the final product BAU manager has thousands of variants to deal with, plus a large contract workforce. Being much larger than the other BAUs in Ratingen, the area is more difficult to coordinate. They are also affected by shortages in components and sub-components.

The customer rarely ordered these parts directly, however, they would order other major products (containing final products as a sub-assembly). SAP helps to send requirements to the different businesses, but it is the micro-scheduling done by hand on each shop floor that caused difficulties as each manager has incentives to optimize his local area.

Solution

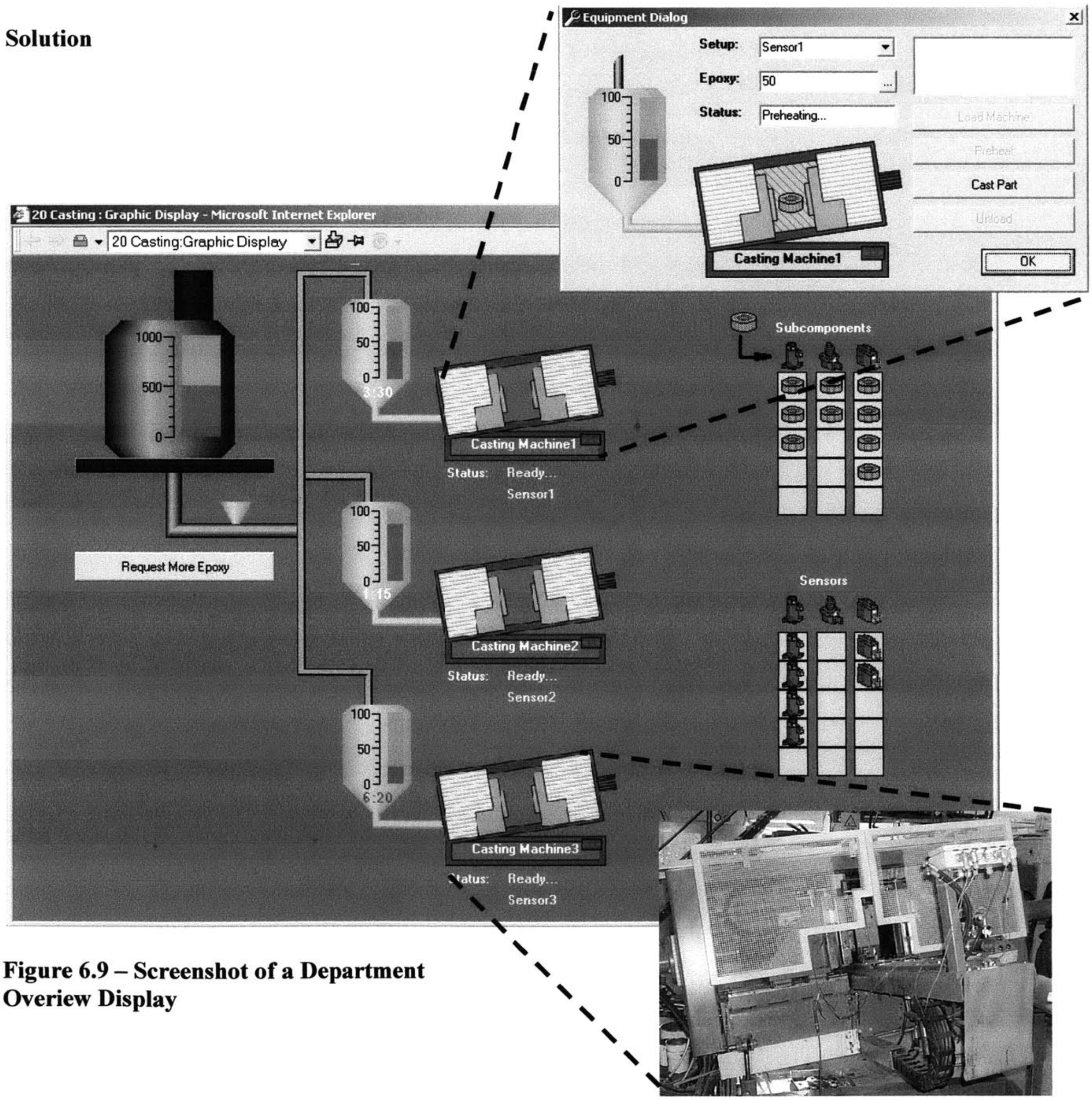

Figure 6.9 – Screenshot of a Department Overiew Display

Figure 6.9 shows a quick glance screen created for the manager of the component plant in Scandinavia. From here, one can check the materials levels in the mixing department, the levels at the machines plus the shelf life of the tank. The machines display their setup and status parameters, and the status of the ConWIP squares (Kanban spaces) are displayed for both subcomponents and finished goods inventories. Again, these types of screens can be built quickly using the Graphic Builder tool with very little code required.

The user can also right-click on the machines to get access to more detailed information or views from web-enabled cameras. The manager can also integrate this information with other aspects built for the machines, such as the preventative maintenance information displayed in Figure 6.10.

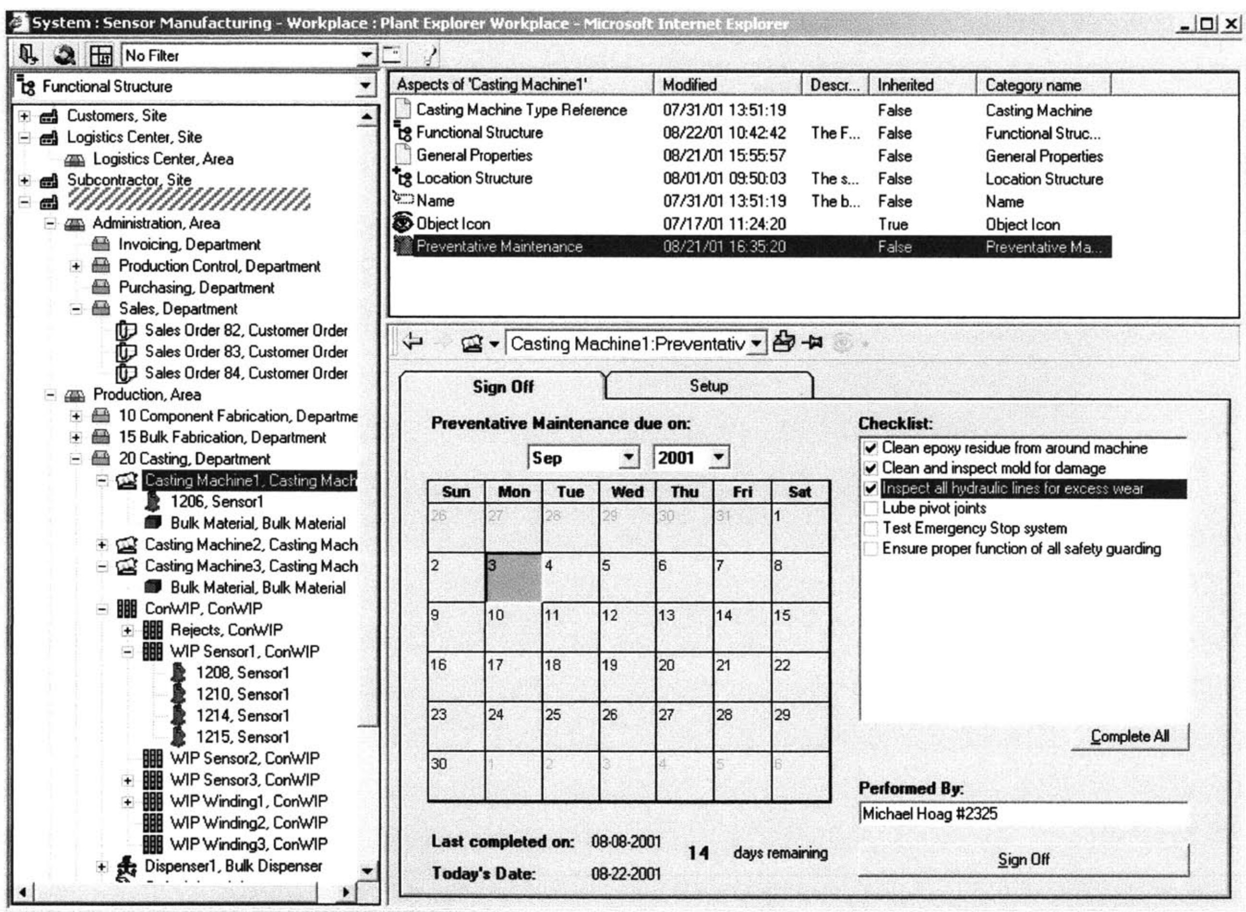

Figure 6.10 – Screenshot of a Preventative Maintenance Aspect

A checklist of preventative maintenance tasks can be displayed with due date, sign-off and status information. This form was implemented as an ActiveX control, wrapped into AIP using Aspect Express.

6.6 Intelligent Documents Reduce Processing Time

Problem

Note: This solution crosses over into typical ERP functionality. The component plant in Scandinavia for which it was developed did not have an ERP system at the time. More importantly, it demonstrates the ability to significantly improve productivity by automating manual data handling activities.

In this situation, customer confirmation of orders can take as long as three days to produce. The division mandate is that this time needed to be cut to 15 minutes or less. This is difficult to accomplish given the large number of tasks the salesman had to perform in order to create the confirmation.

Issues

The plant receives orders in a variety of formats: email, fax, voicemail, post mail, etc. Depending upon the country of origin, the orders may look significantly different. The orders are often consolidated into paper format to be stored in a file cabinet for better accessibility. They are also transcribed into a legacy database system (MIDAS) and also into a shipping database. The order information is turned into requests for production control to be sent to manufacturing. After this point, an order acknowledgment letter is created and sent back to the customer confirming the details of the original order. Thus, the salesman potentially re-enters the order details up to five times.

Related Findings

In Germany, the salesmen have a much more difficult task in determining available to promise (ATP) dates because the customer may order a unit assembled in one BAU, but is made up of components manufactured in two other BAUs. While SAP is fully implemented, the best delivery date is calculated through a process involving up to four people, much of which is done by hand. For example, section 6.5 outlines the difficulties in coordinating orders through the blast furnaces in the sub-component plant. The market is becoming more price sensitive, and therefore salesmen are more regularly getting one-off, large orders for products. Thus, having the ability to automate an ATP date would give the facility a strong competitive advantage [2].

Solution

As discussed in Chapter 2, delays in manual processing can be attributed to inefficiencies, human error and absenteeism. Redundant data transcription is especially non-value added, particularly from one computer system to another. To combat this type of waste, documents can be embedded with business logic to handle quite a lot of these types of tasks. Similar MES solutions have, on average, reduced data entry time by 75% and reduced paper between shifts 61% [8].

In this example, a Purchase Order Object was developed (Figure 6.11) to display order details, held in the Order Properties Aspect, in a familiar format. While not implemented, this object could have been created from an XML enabled web product configurator. (Instead, they are spawned from a VB applet).

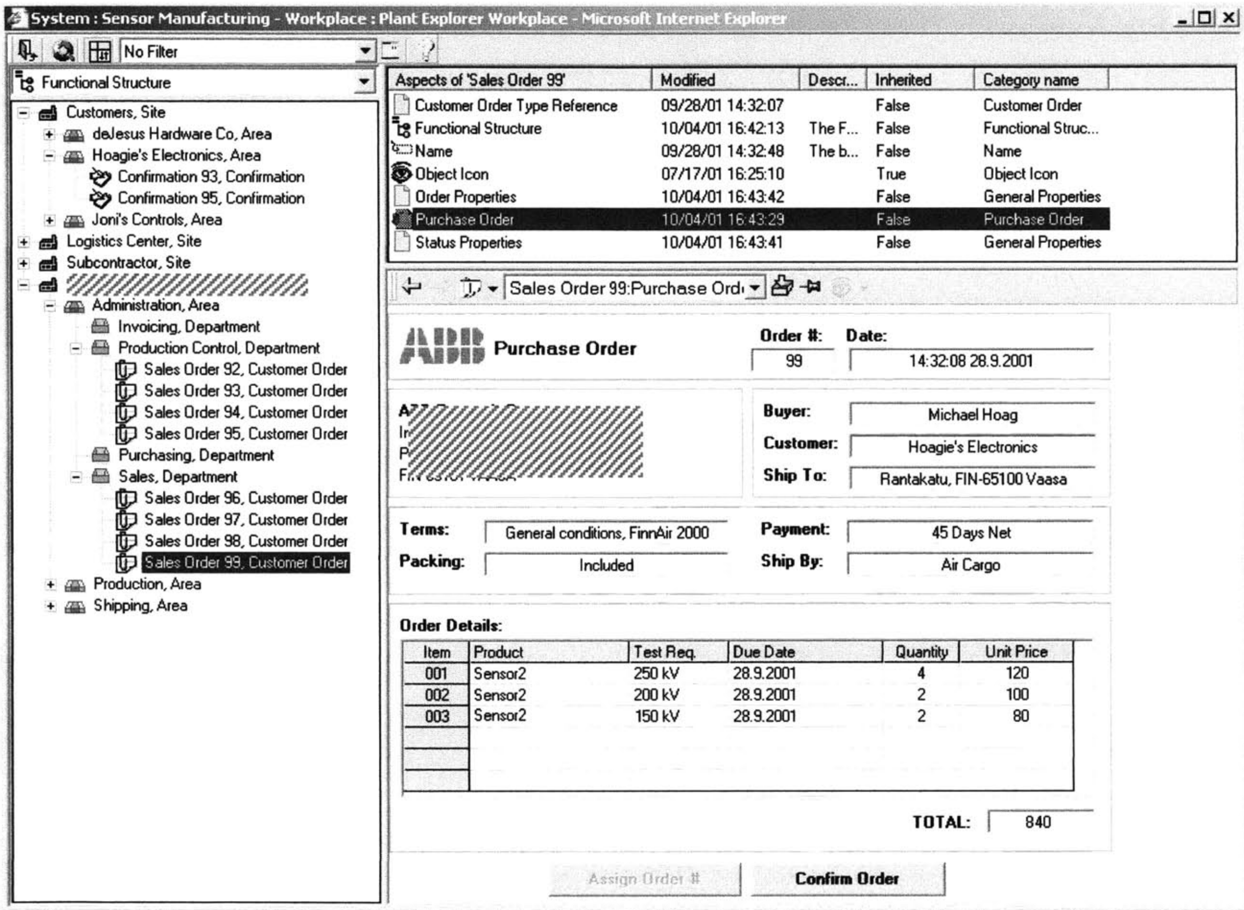

Figure 6.11 – Screenshot of a Purchase Order Aspect Object

When the user selects the "Assign Order #" button, the document is able to:

- Open a new record in the plant's database and return a unique order number
- Transcribe the order details into the database

When the user selects the "Confirm Order" button, the document is able to:

- Create production orders and send them to production control
- Create acknowledgement letters for printing or emailing

It should be noted that the Purchase Order Object does not replace the need for a database because a massive number of objects in the AIP structure will eventually limit system performance. Therefore, these objects are destroyed as the orders leave the plants.

Currently, the business logic is hard coded into Visual Basic as an ActiveX component. A better solution would be to make it generic enough to be configured quickly by any user. This would take a bigger development effort, but would make the solution more easily transferable to the next plant. A technology would be to harness the power of VBA / OLE in an underlying Word document, such that the document can be used regularly even outside of Industrial^{IT}.

While the handling of purchase orders is certainly the responsibility of an ERP-like system, the process for developing this type of intelligent document can also be applied to other types of documents. For example the Quality Test Record in Section 6.2 could be enabled to automatically report to an engineering Aspect System, the production managers screen and to the QA manager as soon as a potential lot failure is detected.

6.7 Chapter Summary

This chapter describes only a few of the Aspect Objects developed during this thesis. Many common themes run through all of these examples. For example, inefficiencies are caused not only by having too little information, but also by becoming swamped with too much information. Any development should focus on the exact needs of each user and the ability to deliver that content *with the minimum effort* on the part of those users. Secondly, a good way to gain acceptance for implementing these types of solutions is to hand a potential user a pencil and a blank sheet of paper and have them tell you what they need to see on a screen. Similarly, it is a good idea to create online forms that look exactly like existing documents so that the system looks more familiar. Third, business needs are different from one solution to the next. The interesting aspect about these solution examples is not so much the functionality that they provide, but the speed at which they were tailored using standard ABB Industrial^{IT} tools. Finally, because the tactical timescale is much faster than the strategic planning timescale, most of the important data comes from the real-time status of some part of the production floor and not some outdated estimate stored as a value in an ERP package.

7.0 RECOMMENDATIONS AND CONCLUSIONS

7.1 Overcoming Barriers to Implementation

A 1995 academic study revealed that enterprise-wide Computer Integrated Manufacturing efforts failed for three main reasons [13]:

- Senior management did not envision Computer Integrated Manufacturing as a competitive advantage that should be implemented in a strategic, "top-down" manner. Consequently, CIM was typically adopted by line managers to increase operational proficiency in isolated functional areas, creating additional "islands of automation."
- Poor technical understanding of Computer Integrated Manufacturing created a lack of commitment by mid and senior-level managers to implement systems on a company-wide basis. The study found that "soft" process concepts such as Just-In-Time and Total Quality Management were much more likely to be embraced by senior management, probably due to their better understanding of key concepts and cost benefits.
- The "bottom-up", piecemeal implementation of Computer Integrated Manufacturing systems created many incompatible systems using proprietary technologies within the same company.

Another survey given in the 1990's of 140 top CEOs was given to determine their companies' largest barriers to Computer Integrated Manufacturing implementations [18]. The results were very similar.

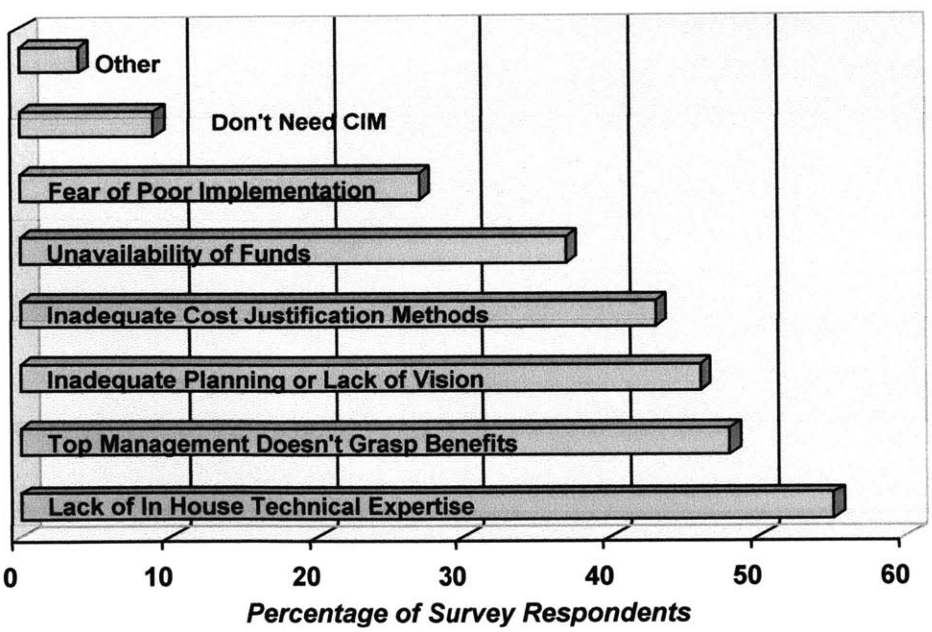

Figure 7.1 – Survey Results from 140 CEOs Regarding Implementation Barriers for CIM

Given the close similarity between the original Computer Integrated Manufacturing vision and the functionalities made possible by Execution and Asset Management solutions, one can reasonably expect similar concerns from top management when faced with investments decision for those Industrial^{IT} solutions a decade later. Therefore, the author recommends that ABB consider the following implementation strategies to combat the potential barriers to e-Manufacturing.

7.2 Addressing "Inadequate Cost Justification Methods" by Driving the Lean Cycle

Historically, CIM implementations were difficult to justify because they often had fixed start dates, but poorly defined end dates [6]. Oddly, many plants today embrace *kaizen* (continuous improvement) activities although these are likewise challenging to assess a payback period for. Clearly, the difference between the two is that the automation of a wasteful process yields a more expensive, wasteful process. By contrast, a clear focus on eliminating or reducing waste has been shown to create real improvement. In this work, the payback for a project in the sub-component plant in Germany to simply automate an existing sales process was estimated at roughly two years. A project in final product plant to improve worker productivity by eliminating non-value added work was estimated at approximately three months.

A popular misconception about lean manufacturing is that it is inherently against the use of computers. Lean became popular in the U.S. at the same time troubles with computerized MRP systems began to surface. Two basic principles of lean are to push control decisions to the lowest levels and to make the real-time status of the shop floor as visible as possible. As MRP does neither function particularly well, it is a simple conclusion to lay the blame on the computer system.

However, low-level control and process clarity are two standard functionalities of most Execution and Asset Management systems. For that matter, it might be possible for lean to be enhanced by computer systems. For example, standard *kanban* (fixed WIP) buffers rely on simple cards to trigger product movements. However, this necessitates line-of-sight proximity, which is not always possible. Further, the operator is responsible for moving and organizing the cards, which affects their productivity. There are no such limitations to an electronic kanban, which can be monitored in the office or even down the supply chain and is able to organize itself.

In fact, there are many potential applications of Industrial^{IT} that could be developed to drive a lean improvement cycle, as shown in Figure 7.2. By focusing on a lean niche market of Execution and Asset Management, ABB should be more able to justify implementation costs.

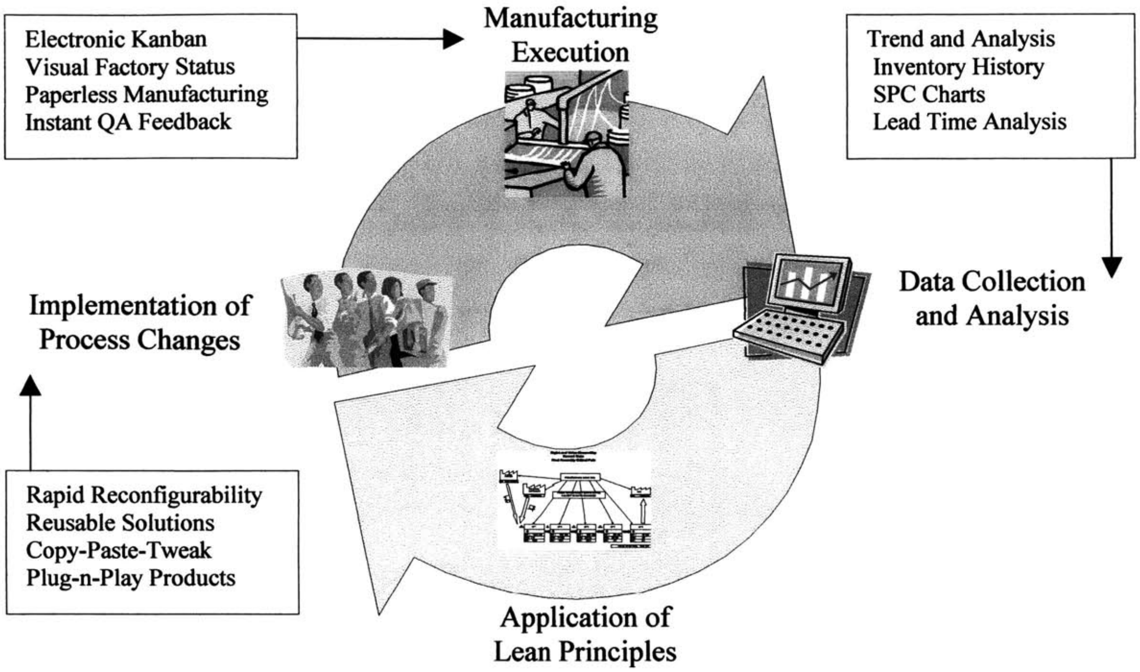

Figure 7.2 – Lean Improvement Cycle Enhanced by Industrial^{IT}

Shown above is the standard lean cycle implemented by Boeing. At the top of the cycle is manufacturing operating in steady state. Boeing's process engineers collect and analyze data from the shop floor to identify areas of improvement. With this data, they will apply traditional lean principles to redesign select processes. Finally, they will implement that process change, including shared learning techniques.

To drive the cycle more efficiently, Industrial^{IT} solutions can be used to measure and analyze factory performance, be used to quickly reconfigure the IT system (as discussed later), and to implement new lean features such as electronic kanbans.

7.3 Addressing "Inadequate Planning or Lack of Vision" with ABB Gate Model

This barrier is actually two slightly different problems. They can both be handled by applying a stage-gate process to a project implementation in the same way that ABB uses their new Gate Model for internal projects. The ABB Gate Model includes seven "gates" where project progress is stopped and reviewed before each major step. This model was successfully used to plan and track the progress of the developments for this research in Germany. The plant managers there preferred this model to the traditional "milestone" approach because the R&D team had to pass 2-3 gates before starting any actual work on the shop floor. It also allowed both the customer and the R&D team to slightly refine the goals of the project as needs were uncovered. Therefore, the Gate Model reduced the risk on the customer side while also reinforcing and refining the project vision and direction at each gate.

This recommendation is for ABB to produce a condensed version of the Gate Model specifically developed for external Industrial^{IT} deployment. This is because the full model involves quite a large number of people and documentation at each stage that may be unnecessary. For example, the Gate Model requires the use of various gate owners, assessors, BA staff, R&D staff, customer staff and a steering committee. Further, the most recently published template for passing a single gate has grown to a 30-page Word document, even before any of the information is filled out.

Lack of vision can also be improved by being selective in whom ABB sends to investigate potential projects. A team of doctoral level computer scientists may miss the operational opportunities if they lack industry experience. A team of process developers may not understand what IT technologies exist to create new solutions if they lack relevant computer skills. They may both be unable to prioritize deployment efforts based on impact to cash flow if they lack an accounting background. ABB should therefore develop cross-functional teams, or recruit resources with hybrid technical-entrepreneurial experience, to lead at least the "discovery" phases of customer implementations.

7.4 Addressing "Top Management Doesn't Grasp Benefits" with a Portable Training Lab

When MRP was first developed, industry was eager to invest in enterprise wide capabilities. As EAM companies now attempt to fill the void left by Enterprise Resource Planning, they are having more difficulty selling their solutions. Three factors are suppressing the sales of Execution and Asset Management applications. First, the failure of CIM and other automation systems to integrate islands of automation in the past has created an attitude of 'if it is not broken, do not fix it". Secondly, the current emphasis on lean manufacturing is often misinterpreted as an "anti-software" activity. Finally, there have been many widespread publication of disappointing and failed ERP / MRP implementations recently.

Therefore, the ability to demonstrate measurable results will be critical for selling these types of solutions outside of ABB. The traditional way to do this would be to build pilot projects in a few ABB facilities. However, it is difficult to see the entire picture on a plant wide scale, and it is inefficient to shuttle all potential customers to site in Poland for a demonstration.

Instead, the author recommends that a portable, simulated manufacturing environment should be developed that can be brought to the customer site and assembled quickly. In a one-day training exercise, this simulated "Jeep" factory can be set up to address particular customer concerns (make to stock vs. make to order, rework loop, parts supply, etc...). By using LEGOs, a number of vehicle types can be designed to model product variants, such as body color, lights and flags, as shown in Figure 7.3.

Figure 7.3 – Pictures of Three Different Jeep Variants

A demand simulator could be made to model customer orders, to track performance and sales, and to create Income Statements for different simulations. Over the course of several simulations, Industrial^{IT} solutions (on laptop computers) can be added to solve various scenarios and the benefits can be measured. The attendees should be able to reconfigure the IT system to redesign the Jeep plant in any way that they wish, especially if the Aspect Systems are designed per recommendation in section 7.5. The course can also be used to introduce a methodology for meshing IT with lean manufacturing, as described in section 7.2.

In this way, ABB can offer a practical, hands-on experience with Industrial^{IT} to top management with maximum convenience and very little risk. (Note: This portable laboratory was designed and built during the Spring semester after the thesis period by the author and 21 colleagues).

7.5 Addressing "Lack of In-House Technical Expertise" with Easily Configurable Solutions

Once an R&D team develops and installs a solution, the maintenance lifecycle of the product falls on the shoulders of the plant. Typically, many plants have a small number of resources that are able to do simple programming (hence the widespread use of Excel-based engineering solutions). However, one should not assume that such resources are available when designing an Aspect System. Therefore, the author recommends that each Aspect System be split into two main parts:

- The core, coded functionality of the Aspect System which acts upon generic object types
- The stored object characteristics for a given implementation, configurable

As a simple example, consider the Preventative Maintenance Aspect shown in Figure 6.10. The underlying code that is used to present maintenance actions to the user, to coordinate with the calendar and to provide system messages when tasks are overdue are hard-coded in the ActiveX control itself. What should not be encoded are the actions themselves, the maintenance intervals or even specifics about the casting machine. These things are handled in a separate tab, as shown in Figure 7.2, that can be secured with a password. (Note: This can also be done in a "Config View")

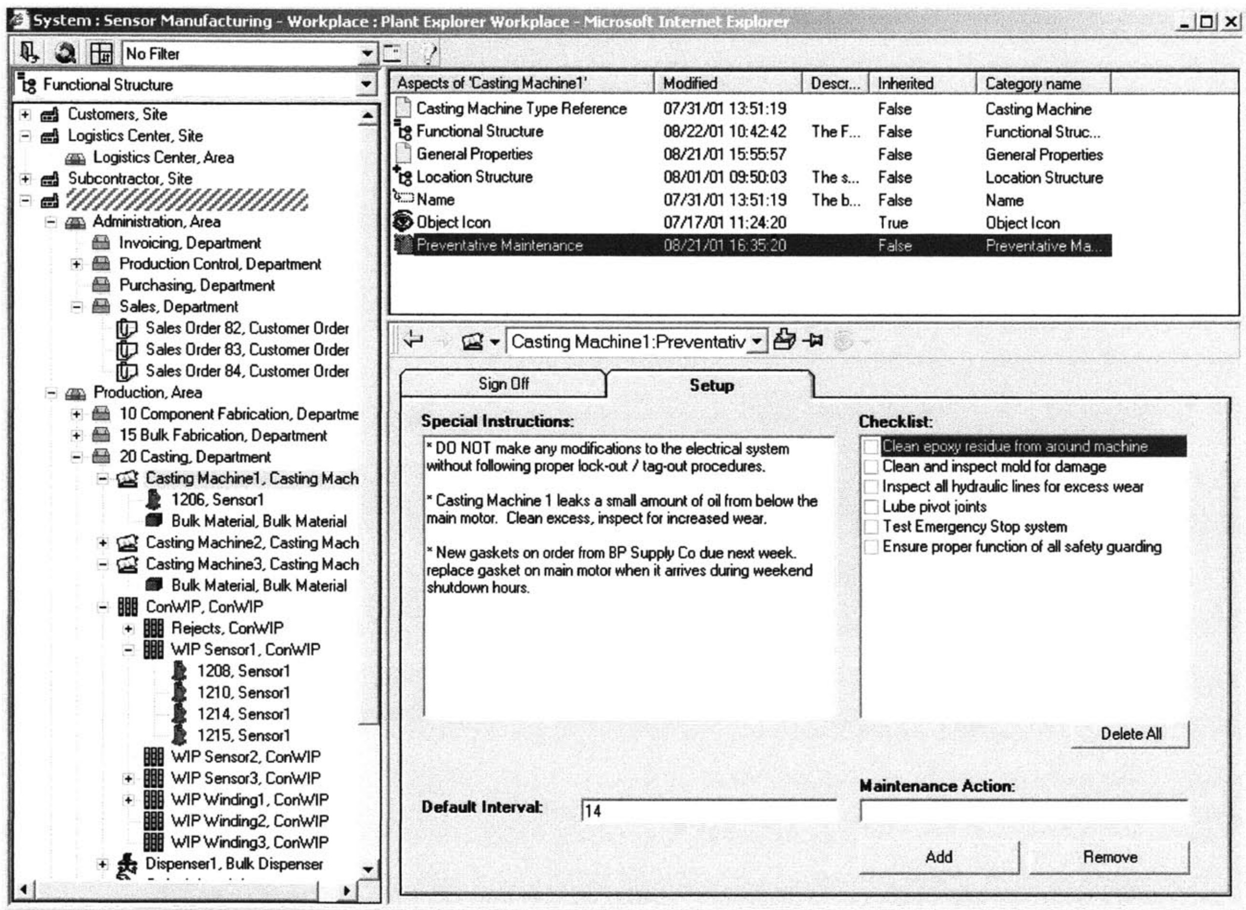

Figure 7.4 – Screenshot of the Setup Tab for a Preventative Maintenance Aspect

There are two benefits to designing Aspect Systems in this way. First, the plant personnel are able to make alterations to the system, without code, as their needs change. The only way to determine how to best do this is to get an end-user involved in the design and layout of their Aspect System. By using familiar Windows controls (text fields, list boxes, etc), the plant does not need to rely on technical experts.

Secondly, the system can be rapidly redeployed for other situations. For example, a "cut-and-paste" operation was done on this Aspect that added it to the thermal ovens in another department. The maintenance on the ovens is done far less frequently, with completely different tasks. However, the setup for changing these features was done in a matter of minutes. Similarly, the entire Aspect System can be exported to a file that can be sent to an entirely different facility via email. This reason alone justifies the additional development cost necessary to make generic Aspect Systems.

This second example shows how the Structures in AIP can be used to help support configurable systems. Consider an assembly workstation in the simulated factory described earlier, as shown in Figure 7.5.

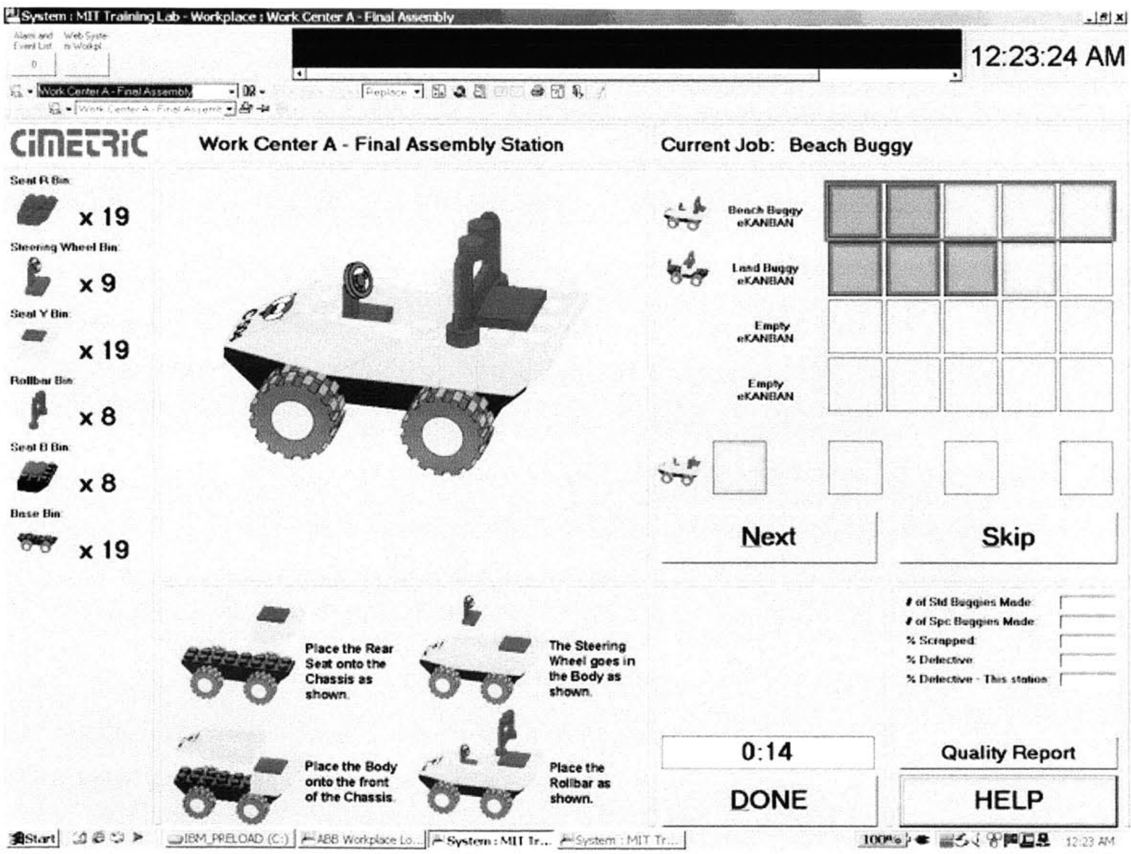

Figure 7.5 – Screenshot of a Workplace for Final Assembly

This workplace displays inventory levels, kanban status, work instructions and other useful bits of information for the Final Assembly station. However, these screens are not hard-coded for individual stations. Instead, they rely on information stored in the Functional Structure of AIP. For example, the parts in inventory are kept as children to an Inventory Bin object. This way, should the plant manager decide to balance the workload by moving certain assembly tasks from one workplace to another, they can simply drag inventory objects from one inventory bin to another.

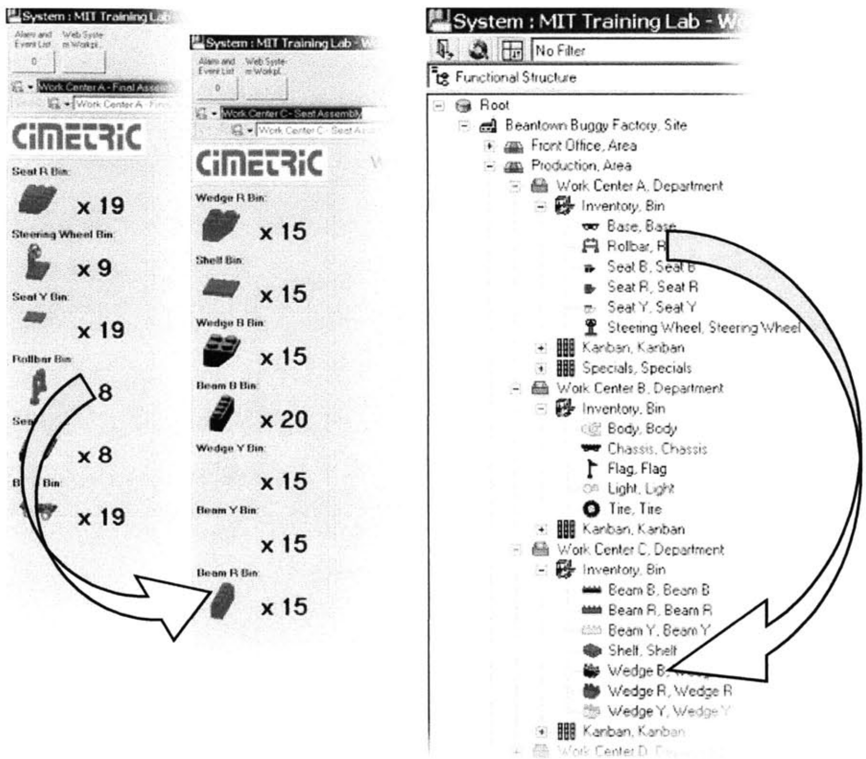

Figure 7.6 – Screenshot Demonstrating How to Reconfigure a Workplace

7.6 Suggestions for Further Research

Clearly, Industrial^{IT} could be used to implement many aspects of e-Manufacturing. This research has discovered that the Execution and Asset Management area, including both Manufacturing Execution Systems and Shop Floor Control applications, is a promising and strategic area for ABB to focus on. Specifically, by developing Industrial^{IT} solutions that enforce lean manufacturing principles, ABB will be able to minimize its risk in following these recommendations.

The next logical steps would be to focus on creating the process for commercializing future developments, to complete a major pilot project, to build up implementation teams, and to continue research on the Lego training course. Further, many of the developments in this work would have benefited significantly by the application of radio frequency identification (RF-ID) technologies. Therefore, a partnership in this area should be investigated.

APPENDIX A: EXISTING BUSINESS INFORMATION SYSTEMS

Supply Chain Management Functions

Sales and Marketing
Contact Management
Selling Scripts
Literature Fulfilment
Event Management
Lead Generation & Pipeline Management
Territory/Team/Personnel Master
Sales Forecasting
Sales Calendars
Marketing Promotions
Sales Statistics & Analysis
Multi-dimensional Sales Analysis

Demand Forecasting and Planning
Historical Sales/Current Demand Detail
Forecast Development & Modelling
Multi-dimensional Forecast Planning
Statistical Forecasting
Forecast Adjusting
Forecast Performance Analysis

Replenishment Planning
Replenishment Basis
Replenishment Computations
Replenishment Generation
Replenishment Analysis
Demand Requirements Management
Repetitive Demand Management

Inventory Analysis & Planning
Replenishment/Inventory Management
Inventory/Requirements Analysis & Planning

Distribution Network Management & Requirements Planning
Distribution Network/Enterprise Modelling
Distribution Network Management & Analysis
Sourcing Analysis
Distribution Requirements Planning (DRP) Parameters
DRP Options
DRP Processes
Planner Options & Actions
DRP Reporting
Replenishment/Inventory Deployment
Dynamic Inventory Deployment
Vehicle Load Planning

Master Planning/Production Scheduling (MPS)
Top Management/Product Line Planning
MPS Parameters
MPS Demand Planning/Forecasting
Master Scheduling Options
Master Scheduling Process
Schedule Simulation
Rough Cut Capacity/Resource Planning
Pegging
Planning Options
Planner Actions/Analysis
On-line Inquiries
Reporting

Enterprise Wide Integrated Requirements Planning
Multi-Site Structuring
Integrated Planning
Integrated Planning Execution

Supply Chain Planning & Scheduling
Supply Chain Modelling
Supply Chain Network Analysis
Planning/Scheduling Parameters
Optimization Planning
Optimization Scheduling & Sequencing
Pegging
Simulated Planning Analysis
Strategic Analysis

Material Requirements Planning (MRP)
Parameters, Policies & Options
Material Requirements Planning
Repetitive Production Scheduling
Supplier Planning/Receipt Scheduling
Project Planning
Pegging
Planner Activities/Workbench
Interactive Planning Simulation & Analysis
MRP Reporting

Capacity Requirements Planning (CRP)
Parameters & Options
Capacity Requirements Loading & Planning
Capacity Planning Simulation
CRP Inquiry & Reporting

Work Center Production Scheduling
Sequencing Options
Scheduling Options
Scheduling Process
Schedule Reporting

Transportation Planning
Shipment/Traffic Planning
Carrier Management
Fleet Management
Site Flow Planning
Shipment Management

Customer Order Management
Customer Profile
Product Profile
Sales Quotations & Order Conversions
Order Entry
Order Processing

Sales Contracts
Customer Planning/Shipment Scheduling
Features & Options-Based Configuration
Rules-Based Order Configuration
Copying
Order Hold Capabilities
Billing/Invoicing and Credit
Returned Goods Handling
Customer Service
Order Management Reporting

Pricing, Promotions & Incentives Management
Standard Pricing
Promotion Pricing
Special Pricing Agreements
Discounting
Pricing Calculation
Advanced Promotions/Deals

Brand Management
Trade Promotion/Spending Management
Trade Marketing/Deal Administration
Deductions Management
Category Funds Management
Brand/Category Analysis

Order Fulfilment ATP & Allocations
Available To Promise (ATP)
Reservations/Allocations

Materials Acquisitions & Supplier Management
Vendor/Supplier Profile
Supplier Rating
Product Profile
Requisitions & Quotations
Purchase Orders
Prices & Discounts
Vendor Contracts/Agreements
Purchase Order Management
Procurement Reporting
Repetitive Vendor Procurement
Procurement Receipts
Quality Inspection & Non-conformance Action

Distribution Warehousing
Warehouse Profile
Warehouse Inventory Controls
Physical Inventory and Cycle Counting
Inventory Audit
Lot/Serial Control
Inventory Adjustments
Inventory Replenishment Orders
Data Collection Inventory Tracking
Receiving
Customer Returns
Put-Away
Order Picking
Shipping
Productivity Analysis & Reporting

Business Management Functions

Accounts Payable Company Policies & Procedures
Suppliers/Voucher Master Data
Invoice Processing & Aging Analysis
Journal Voucher Processing
AR Ledger Posting
AR Transactions & Controls
Payment Processing
Check Processing
AR Reporting

Accounts Receivable and Credit Management
AR Company Policies & Procedures
Customers/Voucher Master Data
Bill Processing & Aging Analysis
Credit Management
Cash/Payment Application, Receipts Processing
Journal Voucher Processing
AR Ledger Posting
AR Transactions & Controls
AR Reporting

General Ledger
GL Parameters & Structuring
Chart of Account Structure
Ledger Development & Maintenance
Enterprise Reporting Structures & Financial Consolidation
Journal Entry
Journal Reporting
Journal Voucher Ledger Transactions
Project Cost Ledger
Ledger Controls
Multicurrency Accounting & Conversions
On Line Inquiry Reporting
Financial Statement Reporting
Additional Financial Reporting
Financial Report Writer
Variance Analysis

Cost Accounting, Management & Activity Based Costing
Cost Data
Cost Allocation Definitions
Cost Allocation Process
Cost Price Calculation
Sales Price Calculation
Activity Based Cost Tracing and Tracking
Activity Based Costing

Project & Contract Management
Contract Administration
Work Breakdown Structure (WBS)
Project Planning Support
Project Budgeting
Project Estimating
Project Costing
Project Progress Accounting & Billing
Project Reporting

Cash Management

Asset Management
Fixed Assets Records
Asset Transactions
Asset Depreciation
Depreciation Books
Revaluation & Interest Calculation
Tax Reporting

Budgeting & Analysis
Budget Controls
Budget Accounting
Budget Development
Budgets
Budget Allocation

Human Resources Management
Recruitment Management
Personnel Profile
Organizational Structuring
Job Position & Wage Profile
Employee Career Development & Training
Reward Management
Budgeting & Cost Control
Government Compliance Reporting
Employment History/Personnel Reporting
Travel Expense Management

Benefits Management
Base Benefits
COBRA Administration
Employee Benefit Plan Profile
Non-discrimination Testing Management
Benefits Administration

Payroll
Employee Payroll Profile
Earnings & Deductions
Eligibility Controls
User Balances
Tax Deductions & Calculation
Payroll Calculations
Payroll & Payment Processing
Check Processing & Printing
Labor distribution & Accounting
IRS Documentation
Payroll & Regulatory Reporting
Security & Audit

Sales Compensation
Salesperson Subledger
Compensation Plans & Commissions
Manual Adjustments
Payment Control

Manufacturing Management Functions

Parameters/Defaults
Manufacturing Defaults

Product Definition/Formulation
Manufacturing-Specific Item Data
Process-Specific Item Data
General Item Data
Item Cost/Price Data
Item Purchase Data
Item Sales Data
Item Production Data
Alternative Data
Resource Definition
Bill of Materials/Product Structure
Engineering/Drawing Bill of Material
Tooling Data
Product/Bill Configuration Management
Bill of Material Support Tools
Formula/Recipe Management

Production Routings
Master Routing Data
Work Center/Capacity Data
Machine Data
Operation Data/Routing Definition
Process Production Model
Company Calendar

Engineering Change Management
Engineering Change Master Data
Engineering Change Order/Notice/Request Data
Engineering Change Control
Revision Level Management
Engineering Change Control in Manufacturing
Formula Change Management

Product Configuration Definition
Product Features & Options
Product Constraints/Rules Matrices
Configurable Objects
Generic Items, Bills, Routings, Pricing
Product Variant Configuration

Product Costing
Item Costing
Costing Activity
Order Costing
Purchase Costing
Costing Calculations
Cost Reporting and Inventory Accounting
Actual Costing
Cost Accounting Variances and Analysis

Quoting & Estimating
Estimating
Quote Processing

Production Management & Reporting
Manufacturing Work/Production Orders
Production Order/WIP Management
Work Order/Operation Completion
Picking
Stock Status/Material Movement
Intersite Material Movement/Transfers

Dispatching/Floor Scheduling
Repetitive Scheduling
Repetitive Production Reporting
Production Monitoring & Reporting/ Activity Reporting
Batch/Lot Reporting
Kitting/Kit Processing

Conformance Reporting
Hazardous Material Reporting
Quality Testing

Project Control
Project Control Definition
Inventory Management by Project
Break-Point Pegging

Inventory Management
Item Inventory Data/Detail
Inventory Forecasting and Simulation
Inventory Calculations & Analysis
Inventory Reporting
Inventory Status
Location Master
Lot Control
Bulk Inventory
Physical Inventory and Cycle Counting
Inventory Transactions
Inventory Valuation
Statistical Inventory Control

Lot/Serial Reporting
Lot and Serial Features
Lot/Serial Where-Used Tracking, Where-From Tracing

Field Service & Support Management
Installed Base
Service Contracts & Billing
Service Call Management
Field Service Management
Returns & Repairs

Computer-Aided-Design
3D Modelling
Dimensioning
User Interface
Support
Display and Visualization
Industrial Design
Sheet Metal Design
Piping
Cabling and Harness
Diagram
Welding

Computer-Aided-Manufacturing
NC Part Programming
NC Tool Path Simulation
NC Part Programming – Mill, Turn, Drill, Wire EDM
NC Post Processing
CMM - Coordinate Measuring Machine
Sheet metal Manufacture

Computer-Aided-Engineering
FEA Modelling
Mechanism
Interface Tools and Standards
Acoustics
CFD Computational Fluid Dynamics
Electromagnetics
Manufacturing
Multi-physics
Optimization
Solid Mechanics
Thermal
Post Processing

Process Management Functions

Supervisory/Cell Control
System Configuration/Development
Data Acquisition
Control
Simulation
Historian and Archiving
Analysis and Diagnostics

Recipe and NC Program Management
Recipe Functions
NC Program Functions
General Functions

Computer-Aided Operator Support
Instructional Guidance
Diagnostic Support
System Tools

Data Collection, Information Management and Reporting
Plant Floor Data Collection and Reporting
Time & Attendance and Labor Reporting
Electronic Batch/Run Reporting
Real-Time Information and Data Management

PC-Based Control Software
Human Machine Interface

Plant Management Functions

Resource Management
Production Management
Resource Monitoring & Tracking
Production Work Flow Management
Resource Performance Analysis
Production Reporting
Cost Accounting, Analysis and Reporting

Finite Scheduling
Finite Production Scheduling
Modelling Provisions
Simulated Schedule Analysis
Schedule Dispatching and Reporting

Maintenance Management
Work Order Management and Reporting
Maintenance Resource Tracking and Control
Equipment History
Purchasing and Service Contracting
Scheduling
Inventory and Other Support Functions

Quality Management Functions

Quality Documentation
Management Responsibility and Reporting
Quality System Manual
Contract Review
Design Control
Document Control
Product ID/Traceability
Quality Records
Internal Quality Audits and Defect Tracking
Training

Supplier Management
Purchasing
Supplied Product

Process Control
Statistical Process Control and Quality Control

Inspection and Testing
Receiving Inspection and Testing
In-Process Inspection and Testing
Final Inspection and Testing
Inspection, Measuring and Test Equipment
Inspection/Test Status & Labelling

Laboratory Information Management (LIMS)

Non-conformance and Corrective Action
Control of Nonconforming Product
Corrective Action

Statistical Analysis
Statistical Techniques

Product Handling and Servicing
Product Storage and Stability
Product Servicing

Cost of Quality

Customer Relation Management Functions

Sales Force Automation
Opportunity and Lead Management

Account Management
Team Selling
Sales Territory and Boundary Management
Sales Quota Management
Quotes
Opportunities Pipeline
Revenue Forecasts
Telemarketing / Pre-Qualification Scripts
Multimedia Encyclopaedia
Shared Customer History Information
Out-of-the-box Standard/Ad-Hoc Reporting
Sales revenue Reports
Account Manager Forecasts
Continent Forecast and Pipeline
World, Country, Region and Territory: Forecast, Pipeline, Sales

Synchronization Schemes & Techniques

Service and Sales Support
Supported Communications Methods
Centralization

Call Center Management
Call Center Integration
Call Tracking

Service Management
Service Level Agreement
Problem Resolution
Cross Selling and Upselling
Telesales
Performance Measurement

Field Service
Communications

IT Help Desk
Asset Management

Marketing Automation
Databases
Targeting
Segmentation
Profiling
Handling Campaigns
Extraction
Campaign Optimization
Response Analysis

Price Setting

Implementation and Training
Vendor Provides Implementation Services
Training Services

Support
Call Center
Application fix response time
Problem Resolution

APPENDIX B: KEY COMPANIES AND THEIR TECHNOLOGIES

Company	Technology
ABB	Software infrastructure (Industrial^{IT})
Accenture	Consulting
Advanced Digital Research, Inc.	Ethernet / DNC hardware
AlterSys	Open, embedded controls
American Software, Inc.	Enterprise resource planning, supply chain management
Apriso (Cim Vision)	Plant automation, wireless
Aspen Technology, Inc.	Integration & workflow software
Baan (Invensys)	Enterprise resource planning, Supply chain management
Brooks Automation	Supply chain management, Material handling
Camstar	e-Manufacturing, supply chain execution
Cisco Systems	Hardware infrastructure
Compac	Hardware infrastructure
EDS	IT, Manufacturing consulting
e-Manufacturing Networks, Inc.	CNC Ethernet-based networking platform
Datastream	Execution and asset management
DEC	Automation
Emerson	Automation, process control
Entivity	Automation software solutions
Enginuity	Collaborative product management, Mfg. execution systems
Epic Data	Wireless applications
Foxboro Company	SCADA
General Electric (GE Fanuc)	Hardware infrastructure, interfaces, software
GE Cisco Industrial Networks	Hardware infrastructure
GenRad Inc	Performance-assurance technologies
Honeywell POMS Corporation	Mfg. execution systems
Hewlett Packard	Hardware infrastructure
i2	Supply chain management, collaborative planning and scheduling
IBM	Hardware infrastructure
IFS	Enterprise resource planning, MES
IndX Software Corporation	Decision support software
Intellution	Mfg. execution systems / SCADA
Intermec Technologies Corporation	ADC and mobile computing
J.D. Edwards	Enterprise resource planning, supply chain management
Lantronics	Device Servers
Lighthammer	Manufacturing intelligence portals
Made2Manage	Enterprise resource planning, CRM / SCM
Manugistics	Supply Chain Management
MDSI	Open software control and automation
Microsoft	Software provider
Optiant	Inventory management
Oracle	Enterprise resource planning
PeopleSoft	Enterprise resource planning, collaborative planning and scheduling
Raytheon Professional Services	Consulting
Rockwell Automation	Hardware infrastructure
SAP	Enterprise resource planning, Supply chain management
Schneider Electric & Automation	Modicon automation
Selectica	Customer relation management
Simantic Net (Siemens Automation & Drives)	Industrial software
Software Horizons Inc.	PC based industrial applications
Sun Microsystems	Solarus OS, networking
Symbol Technologies	Barcoding, wireless LAN
SynQuest, Inc.	Supply chain management
USDATA Corporation	Mfg. execution systems
Verano	e-Business platforms
Wonderware (Invensys)	Mfg. execution systems / SCADA

GLOSSARY

Application – See *system application* and *user application.*

Application Server – Server that runs system applications, such as the AIP Web Server, Enterprise Historian, Batch, Asset Optimization, Process Optimization, Simulation, and also third party and user provided applications

Architecture – A description of the rules and recommendations, which a software component that is compliant with the architecture, must obey.

Aspect – A representation of a facet of a real world entity, which entity is represented as an Aspect Object. An aspect defines a piece of information, and a set of functions to create, access, and manipulate the information.

Aspect Category – A specialization of an aspect type. For example, the aspect type Graphic Display includes the categories Overview, Group, and Object Display.

Aspect Framework (Afw) – Platform functionality that supports integration of aspect systems and connectivity components, including concepts, APIs, and tools.

Aspect Integrator Platform – A collection of software that forms the basis for an Industrial^{IT} system, and provides the development and run-time environment for Industrial^{IT} solutions, including the Aspect Framework.

Aspect Object – Aspect Objects are representations of real world entities, such as a valves, motors, robots, transformers, reactors, products, material, production orders, batches, customer accounts, etc., with which a user interacts. Different facets of these real world entities are modeled as aspects. An Aspect Object is not an object in a strict sense, e.g. like a COM object, but rather a container of references to implementations of its aspects.

Aspect Object Type – An Aspect Object type defines certain characteristics that are shared between several Aspect Object instances, such as a basic set of common aspects. This makes it possible to create and efficiently re-use standardized solutions to frequently recurring problems. For example, rather than building an Aspect Object from scratch for every valve in a plant, you can define a set of valve types, and then create all valve objects as instances of these types.

Aspect Server – A server that runs the central functions of the Aspect Object architecture, such as Aspect Directory, Structure and Name Server, Cross Referencing, File Set Distribution, etc. The Aspect Server is normally used as the Windows domain controller for the control and client/server networks.

Aspect System – A software system, which implements one or several Aspects.
Component – A re-useable piece of software or hardware. See also *system application*
Connectivity component – A connectivity component provides access to real time data, historical data, and/or alarm and event data, from a certain type of device.

Aspect system object (ASO) – A COM object through which an aspect system provides (part of) the functionality associated with an aspect type. This COM object supports certain framework-defined interfaces, through which the application can initiate and participate in common operations on Aspect Objects and aspects.

Attribute – A data field that is associated with an object (in the general sense, not Aspect Object) and can be accessed through a special purpose method call or API. Note: This definition makes properties a subset of attributes.

Client application – Client applications are applications that utilize the functionality provided by one or more Afw Services, e.g. to present some information to a user.

Client/Server network – A client/server network is used for communication between servers, and between workplaces and servers.

Composite Aspect Object – An Aspect Object instance that contains other object instances. This containment is implemented by having other objects as children in one or more structures where the composite object is placed. The set of objects placed under the composite object are the children of the composite object. Usually the term "composite object" means a composite object including all its children.

Composite Aspect Object Type – A composite Aspect Object type describes a set of Aspect Objects organized in a structure, with a parent object and one or several child objects. The children in a composite object type are called formal instances, because they inherit from object types defined elsewhere in the Object Type Structure, but they are not actual instances. When a composite object is instantiated actual instances are created for these child objects.

Computer Integrated Manufacturing (CIM) – An early attempt to integrate and control manufacturing operations by computer that later became the basis for Execution and Asset Management systems.

Connectivity component – A connectivity component provides access to real time data, historical data, and/or alarm and event data, from a certain type of device.

Connectivity package – Connectivity components, up-loader, supporting aspect systems (e.g. for configuration), and graphical elements, faceplates, Aspect Object types, etc., bundled together to provide the integration of a certain type of devices into the IIT system.

Connectivity Server – A server that provides access to controllers and other sources for real-time data, historical data, and alarm and event data. A Connectivity Server runs services related to OPC/DA, APC/AE, OPC/HAD, and SysMsg

Control Network – A control network is a local area network (LAN) optimized for high performance and reliable communication with predictable response times in real time. Control network devices and servers are connected to the control network. For performance and integrity reasons, connection of other systems to a control network is restricted.

Control Network Device – Device connected through an Industrial^{IT} supported control network. Examples are controllers, robots, variable speed drives, etc.

Customer Relationship Management (CRM) – CRM applications generally aim to improve customer value by making a business more responsive, visible and flexible.

Device – An entity that in some form of dedicated environment provides part of the functionality of certain aspects.

DTM – Device Type Manager is device dependent knowledge packaged into a component that can be plugged into an FDT framework. The DTM includes everything needed to configure and maintain the device via the fieldbus it is connected to.

Enterprise Resource Planning (ERP) – ERP systems are designed to integrate many of the operational functions of a manufacturing plant, including planning, scheduling, human resources and finance.

Execution and Asset Management (EAM) – EAM includes shop floor control and manufacturing execution functionalities. These types of solutions guide, initiative, respond to and report on activities in manufacturing using current and real-time data.

Faceplate – A faceplate is an aspect that provides a graphical representation of a certain Aspect Object, with presentation of certain properties related to the object, and mechanisms for operator interaction such as on/off, increase/decrease, etc. Aspect Object types often include several different faceplate aspects, providing different presentation and interaction possibilities. See also *object display.*

FDT – Field Device Tool is a framework into which DTMs can be inserted. This provides a common environment for all fieldbus devices

Fieldbus – A fieldbus is used to interconnect field devices, such as I/O modules, smart sensors and actuators, variable speed drives, PLCs, or small single loop devices, and to connect these devices to the Industrial^{IT} system. Fieldbuses are normally open for connection of devices from other vendors.

Fieldbus Device – Device connected through an Industrial^{IT} supported fieldbus. Examples are remote I/O and smart sensors and actuators, but also controllers, robots, variable speed drives, etc., when these devices are connected through a supported fieldbus.

Generic Device – A device that is connected to an Industrial^{IT} system through other means than Industrial^{IT} supported control networks and fieldbuses or Web servers. Examples are devices connected through OPC servers or Modbus and similar protocols.

Graphic display – A graphic display is an aspect that provides a visual presentation. It consists of static graphics representing for example tanks, pipes, etc., and graphic elements that present dynamic information. Graphic displays are often used to present the state of a process or a part of a process, but are useful in any context where dynamic graphical information needs to be presented. Examples of predefined graphic display categories are Graphic Display, Overview Display, Navigation Display, Status Display, etc.

Graphic element – A graphic element is an aspect that is associated with an Aspect Object type, to be used in graphic displays to present dynamic information for instances of that type. An object type may have several different graphic element aspects to allow the user to select among different visual presentations.

Industrial^{IT} (IIT) – Umbrella concept for ABB's vision for enterprise automation.

Industrial^{IT} Architecture – The architecture of the Industrial^{IT} system. The architecture defines how the system is built, in terms of basic concepts, underlying technologies, system topology, modularity, and mechanisms for interaction between different parts of the system. It also defines concepts, rules, and guidelines that a component must comply with in order to fit in the Industrial^{IT} system. A central feature of the IIT architecture is that information and functions are centered on Aspect Objects.

Industrial^{IT} Certification – The process of verifying that Industrial^{IT} products comply to the requirements to make them Industrial^{IT} enabled. The certification looks at how well a product can fit together with other products in an Industrial^{IT} solution

Industrial^{IT} Enabled – A product that is Industrial^{IT} enabled has been verified according to the process of Industriall^{IT} certification. It has the right to use the "Industrial^{IT} enabled" symbol

Industrial^{IT} System – A computer system that implements (part of) the Industrial^{IT} vision.

Industrial^{IT} System Offering – A defined offering to the market of Industrial^{IT} products intended for a particular area of application or use. The products that are included in an Industrial^{IT} offering are verified together, and the resulting system has a defined behavior, capacity, and performance.

Node – A computer on the Internet, Intranet, plant or control network, typically running Microsoft Windows 2000 or ABB real-time operating system.

Object Display – An object display is an aspect that provides a graphical representation of an Aspect Object, with a comprehensive presentation of the object's properties. Interaction mechanisms include support for tuning, calibration, etc., in addition to operator related interaction such as on/off, increase/decrease, etc. See also *faceplate.*

Object Trend – An object trend is an aspect that provides a curve representation of historical values of certain properties of an Aspect Object.

OPC – OLE for Process Control. A standard for data access between devices and the workplace level. It currently specifies data access (DA), alarm and event access (AE) and historical data access (HDA)

Plant Network – A plant network is used for communication between servers, and between workplaces and servers. The plant network is open for connection of other systems.

Platform – A standardized foundation on which to build products

Product – A product is something that is offered to the market as an own entity. It has specified functionality, performance, capacity etc and is consistently handled through its total life cycle

Property – A data field that is associated with an Aspect Object that can be accessed through OPC using the standard Aspect Object item syntax.

Solution – A configuration of software and hardware components that solves a certain class of problems. The design and functional scope of a solution should be optimized to make it re-usable in a practical way.

Supply Chain Management (SCM) – For the purposes of this thesis, SCM is taken to mean computer applications that assist with material procurement, reducing logistics and inventory levels, and generally improving communications with suppliers and partners in the value chain.

System Application – A software package or component that provides functionality within the Industrial^{IT} solution portfolio. System applications cooperate according to rules defined by the Industrial^{IT} architecture, using mechanisms provided by the Aspect Integrator Platform. They are normally bundled into System Products or System Product Add-ons. To participate in Aspect Object operations, and thus be an integrated part of an Industrial^{IT} system, a system application must present itself as one or several Aspect System(s).

System Product – A System Product consists of system applications bundled together with relevant parts of the Aspect Integrator Platform. It is complete from installation point-of-view, and requires only Windows 2000 or similar. Several System Products can be installed on the same physical node.

System Product Add-On – A System Product Add-on consists of one or more system applications that are bundled as an extension to one or several existing System Products

System product extension – A System Product Extension consists of one or more applications that are bundled as an extension to one or several existing System Product. A System Product Extension can only be installed if (one of) the corresponding System Product(s) has been installed previously.

Thin Client – A thin client is a web browser connected to the Internet (or Intranet). It does not require any preloaded software. It supports ActiveX controls, but it communicates with the Industrial^{IT} only through Internet technologies. Internet Explorer is used as browser.

Ultra-Thin Client – An ultra-thin client is similar to a thin client, but any web browser can be used. It does not have to support ActiveX, and it does not make any assumption about screen sizes. A typical ultra-thin client is a PocketPC.

User Application – A software configuration that applies to a specific problem, e.g. a specific process control problem. A user application consists configuration data and programs written in the supported languages for the device or product for which the application applies. It can consist of a set of Aspect Object instances, with parameter values and other configuration data for the Aspects, e.g. control logic, process graphics, alarm and event specifications, reports, maintenance data, etc. When there is no risk for confusion with system application, the term "application" may be used instead of "user application".

Web Device – Device that includes a web server through which information and functionality of the device is accessed.

Workplace – A user interface for a function. Different workplaces can be built for various purposes. The Workplace is the main user interface for the Industrial^{IT} products.

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