CHAPTER 5

Computing infrastructure for e-manufacturing (software/hardware perspectives)

Z.Y. Wang, K. Pusthay & A. McCracken
Department of Mechanical Engineering,
University of Nevada at Las Vegas,
Las Vegas, NV 89154, USA.

Abstract

This chapter discusses the history and current development of the computing infrastructure for e-manufacturing. Most commonly used software tools and hardware for e-manufacturing are presented, and their applications in CNC, CAD/CAM, MRP/ERP/CRM are discussed.

1 Introduction

The infrastructure for e-manufacturing has been evolving rapidly from the primitive punchcard-based computing system in the 1950's to open architecture systems that run on today's UNIX and PC platforms. Many researchers in the manufacturing field consider the invention of the first NC machine by John Parsons and Frank Stulen at MIT as one of the first major milestones in e-manufacturing history [1].

During the 1950's, following the invention of the computer, John Parsons realized the potential application of using the recently created computer for milling operations [2]. He, along with Frank Stulen, determined that the surfaces of an airfoil could be described mathematically, and then repeated to shop workers for positioning of the milling equipment. This early technology was called Motor Controlled Apparatus for Positioning Machine Tool; the name was later on shortened to Numeric Control (NC). Figure 1 is a picture of the machine.

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These first NC machines were developed in large part through funding from the United States Air Force, and were used for military purposes.

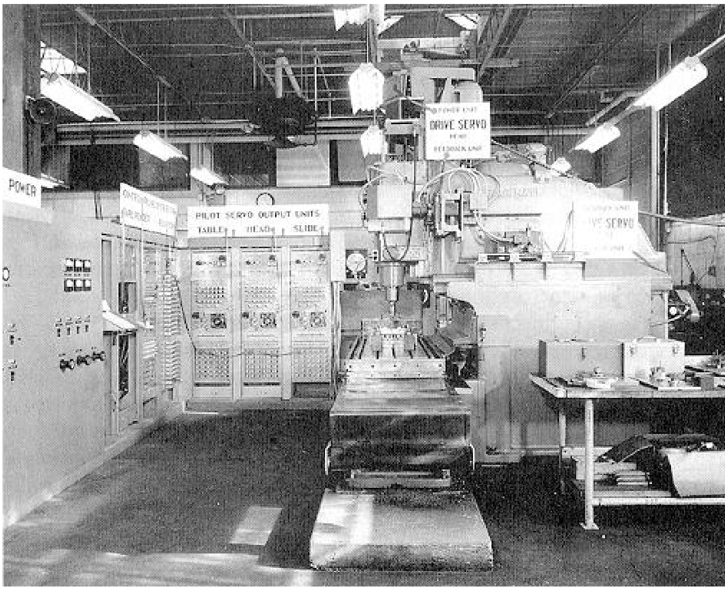

Figure 1: First CNC milling machine developed at MIT.

Others soon realized that instead of reading off lists of co-ordinates, these lists could be programmed using punchcards, allowing the milling machine's operator to feed these cards into the machine and recreate a machine part identical to other parts. The cards, or code, could be altered to derive a new or updated part. These machines brought new difficulties though, as the number of proficient NC machine operators was limited, and the cost of maintaining hardware was high. As computers became less expensive and more accepted, manufacturers realized that these machines could be utilized to store the data of punchcards on their magnetic tape surfaces.

Many significant changes in computing infrastructure for manufacturing have taken place since the invention of NC machines, paralleling the advances in computer technology. CNC machines are often used as a good example to showcase the changes. In general, people believe that the computing infrastructure for NC machines has evolved three generations over the past 40 years:

- 1st Generation, simple point-to-point movement. Programs created and stored on paper tape.
- 2nd Generation, a microprocessor was used to generate and co-ordinate motion. More complex tool paths such as circular and helical

interpolation were supported. Most tool path programs created and stored in G code format. Complex tool paths were generally created off-line on a PC based CAM system and downloaded over RS232 from the PC to the machine tool.

- 3rd Generation, full power of a personal computer on the machine. The PC is the control. Full power and complexity of off-line CAM integrated with machine tool control. Leverages economy of scale of PC hardware, operating systems, and software development tools. Allows user to maintain and service control [3].

As computers increased in speed and computational power, the ability to add real-time feedback from the CNC machine became possible. The 1st generation 8080, developed in 1974, had 6,000 transistors while Pentium 4 has more than 20,000,000 transistors. It has increased nearly 4,000 times in the last 25 years. The Memory Chip size also has been increasing from 4k to 128M (32,000 times) [4]. Sensors mounted on the machinery were capable of detecting the position of the object being machined as well as the torque, speed, and other attributes of the machine itself. Utilizing cameras, sensors, and other detection equipment increases the accuracy and precision of machined parts [5].

Simultaneously, the developments in computer aided design and manufacture (CAD/CAM) software packages were moving along at a steady pitch. Initial implementations of CAD systems were available as early as the 1960's with a program called Sketchpad, and the first industrial application integrating CAD and CAM was probably General Motor's DAC-1 (about 1963). Though these systems had been developed, they still suffered from poor performance because of the limitations of hardware in performing extremely complex mathematical computations [6].

CAD/CAM systems continued to develop through the 1980's and 1990's with improved interaction between the two. The merging of the two led to a new term, Computer Integrated Manufacturing (CIM). Early CIM systems were in use early in the 1980's [7]. These performance improvements drove manufacturers to more efficient systems and also drove software and hardware developers to make products that gave a competitive edge.

In the mid 1990's, Internet-based technologies fundamentally changed the computing infrastructure of manufacturing industry. CAD, CAM, CAPP, and CNC began to evolve from PC-based to Web-based systems. They are built on client–server architecture and implemented on the JAVA platform. WebNC, for example, has three functional modules, NC Check, NC tutor and NC Reverse Engineer. On the client side, the NC check module captures errors in the input part program and gives suggestions for revising the code, and NC tutor gives block-by-block explanations of the code. On the server side, NC Reverse Engineer analyses the code in the reverse engineering fashion to extract the geometric and machining data of various part features being machined. NC Check and NC tutor are implemented using JAVA applets and NC Reverse Engineer is implemented on Java servlets on the server side. Ease-of-use has greatly increased with the latest generations of conversational part programming.

This is but one example of the vast opportunities for integration between the Web and the manufacturing industry.

2 Software tools

Software plays a vital role in the computing infrastructure for integration of computers with manufacturing. It drives the computers and the machinery, making it a critical component. Software also assists in the design process for CAD/CAPP/CAM. Software makes analysis such as finite element analysis a possibility, utilizing the computer's processing power to analyse geometries and relationships.

Figure 2 illustrates a paradigm of the Internet-based distributive software system. A software package is loaded on a server A, or is distributed among multiple server systems A, B, and C through the mechanisms of partitioning and replication. A remote user or client X makes a request for the execution of the software and may pass a set of argument values to it. The requested messages pass through the local network X, the regional network m, then through the Internet backbone to the regional networks k, l and m, finally reaching the servers A, B, and C through their local networks.

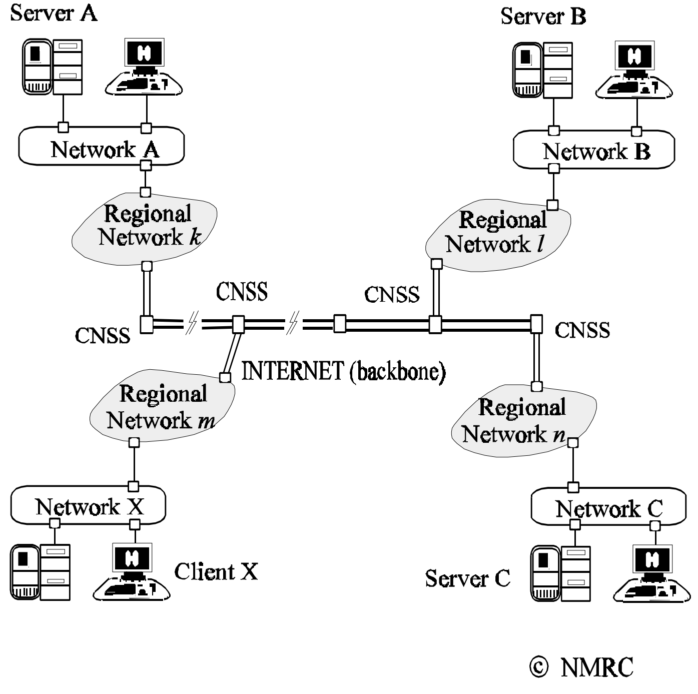

Figure 2: Paradigm for an Internet-based software system.

Currently, there are a wide variety of network architectures in use such as TCP/IP, DECnet, SNA, OSI, AppleTalk, and Novell IPX, each having its own network transport mechanism. For the most part, all of these network transport mechanisms provide a similar range of functions. The message transmission from the client to the servers operates in an identical manner no matter what network architecture is used at the transport level.

The method for implementing the distributed software system is based on client-server architecture using the Data Transfer Mechanism (DTM) library to transfer data between the simulation program and the client program.

DTM uses "ports" to allow two programs running on two different machines to communicate with each other. Input port receives data while output port sends out data. In order to communicate, the client and simulation program, both open input and output ports and the input port of the client program, is tied up with the output port of the simulation program and vice versa. Through these two tie-ups the two programs can send data back and forth using the DTM library. Each message consists of a header and a body. The body contains any data that needs to be sent, i.e., actual variables.

The client and simulation programs follow a certain protocol to communicate with each other. This protocol enables the simulation program to understand the inputs that the client program is sending and vice versa. A server program runs on the machine on which the simulation program resides. This server program is always listening at a known port number for connections. The simulation program is extended to be able to communicate with the protocol.

The single connection between the simulation program and the client program is called a run. A run consists of a number of requests. Each request is one run of simulation program based on some input parameters. In the input section the client program sends in the input parameters it wants the simulation program to use. In the output section it asks for the output it needs. If the input section is missing the simulation program assumes default values for all input parameters and if the output section is missing it sends back all the output it generates. The client program can either send in another request or close the connection. The client needs to know the specific port number to contact the server at. The final connections are between the client and the simulation program and the server plays no part in this.

The first stage of communication protocol is illustrated in Figure 3. The client program opens an output port and connects that port to the port number at which the server program is listening. The client program also opens the input port to which the simulation program can later connect. The client program sends a DTM message with the name of the simulation program and the number of the input port at which it is listening. This is interpreted by the server program to mean that the client wants to run the specific program and that the program can contact the client back at the port number sent. The server now starts up the simulation program. The simulation opens up an output port and connects it to the input port that the client sent. Next the simulation program opens an input port and sends this port number to the client program through the now established connection. The client program closes its output port connection with the server program and opens another output port connection to the input port it received from the simulation program. This frees up the server's port for other client connections. At this point both the client and simulation programs have one input and output ports each connected to each other's input and output ports respectively.

Now the simulation program sends in a DTM message that is verified by the client program to ensure that both are following the same protocol. The client program then sends the message indicating to begin the run.

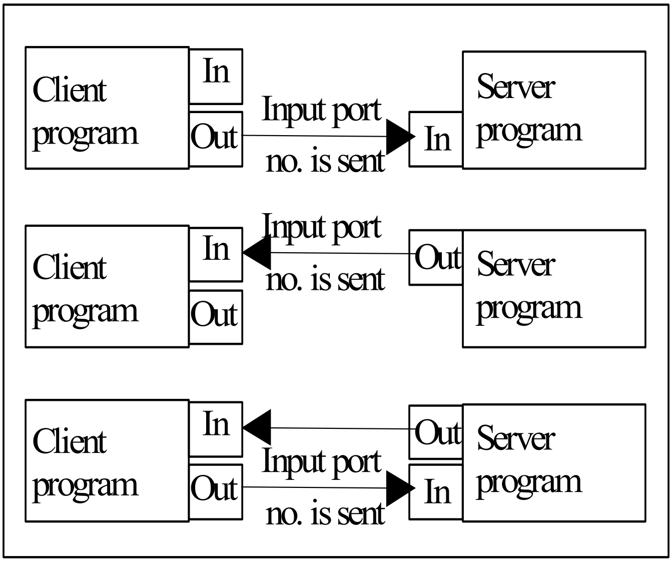

Figure 3: Connection between client and server programs.

The second stage begins when the client program sends the request to begin the input section. In the input section the client program sends in various DTM messages containing a variable name in the header and its value in the data portion of the message. The variable names correspond to the various parameters that the program requires. The client program requests the output session by sending in various messages consisting of variable names of the output that it requires. After the input and output section, the simulation programs send in a message to end the request. This concludes the second stage of the protocol and signals the simulation program to run the simulation based on the inputs sent and send back the output requested in the third stage of the protocol. The client program can either begin a new request or it can close the connection by sending in the message to end the run.

The structure of the three-stage communication protocol between client and simulation programs is shown in Figure 4.

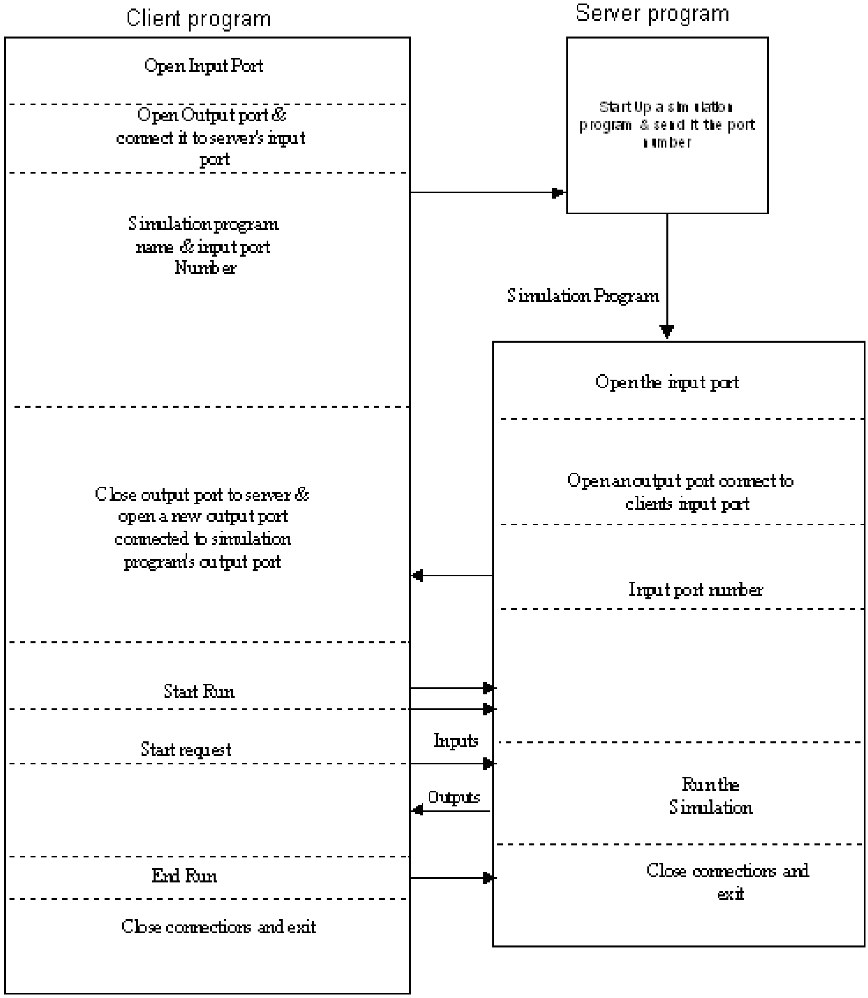

Figure 4: Internet-based Distributed System Software protocol.

Most of the commercial software used in e-manufacturing field is based on client-server architecture discussed above. The evaluation criterion of selecting software for implementing e-manufacturing is discussed in Table 1. The evaluation emphasis on integration to CAD/CAM/CAP systems, integration to ERP/MRP/SCM/CRM systems and lastly the evaluation is based on the system architecture. This evaluation criterion helps the end user, normally a manufacturing enterprise, to select the software that suits their working environment. Presently the software available in the e-manufacturing field can be classified into the categories of MRP/ERP/SCM, CAD/CAPP/CAM, etc. Table 1 is a list of some of the software tools in e-manufacturing, and more detailed discussions are given in the following sections.

Table 1: Software tools used in e-manufacturing.

Category	Software	Vendor	Head-quarters	Website
CAD Systems	Pro/e AutoCAD Pro/Intralink CADDSS Unigraphics Catia Ideas W Logic Mentor graphics	PTC AutoDesk PTC -- Electronic Data Systems IBM Electronic Data Systems Mentor Graphics	MA, USA CA, USA MA, USA -- Texas, USA USA Texas USA OR, USA	www.ptc.com www.Autodesk.com www.ptc.com www.eds.com www.catia.ibm.com www.eds.com www.mentor.com
CAM Systems	Master CAM Surf Cam Work NC	CNC Software, INC Surf Ware Sescoi	CT, USA CA, USA MI, USA	www.mastercam.com www.surfware.com www.worknc.com
CAPP Systems	CIMX HMS-CAPP LOCAM	CIMX HMS-Software INC LSC Group	Ohio, USA MA, USA UK	www.cimx.com www.hmssoftware.com www.lsc.co.uk
MRP/ERP/ SCM Systems	Baan Oracle People Soft SAP Manman IFS J D Edwards Kewill Lawson Software	Baan Oracle Corporation People Soft SAP Manman IFS J D Edwards Kewill Lawson	Netherlands CA, USA Pleasanton, USA Germany Sweden Denver,CO,USA Cheshire, UK St Paul, MN, USA	www.baan.com www.oracle.com www.peoplesoft.com www.sap.com -- www.ifsworld.com www.jdedwards.com www.kewill.com www.lawson.com
System Architecture	Client/Server archircture Open componetized STEP PDM (product Data management) Internet architecture	_ Cad-cadkey, Unigraphics SGI Alias, Bentley, Intergraph. CAE vendors-technomatix, dened PDM vendorsIman, BoeingDCAC/MRM (metaphase		

2.1 Software tools for MRP/ERP/SCM

Enterprise Resource Planning (ERP) are software systems that attempt to integrate all departments and functions across a company into a single computer system that can serve all those different departments' particular needs. Typical configurations include modules to support human resources, accounting, payroll, and other corporate services. Additional modules may be added to support the particular company. Supply Chain Management (SCM) and Manufacturing Resource Planning (MRP) may be separate software packages, but for total integration of the enterprise, can be added as modules of ERP. Manufacturing resource planning is essentially a portion of the ERP system with modules specific to manufacturing, including warehousing, shipping, and production scheduling. Some of the most popular software tools are introduced in the following sections.

2.1.1 Baan

Baan operates on client-based architecture to tightly integrate growing demands of the manufacturing industry and to collaborate efficiently with its supply chain and across its value stream. The advantages it comes with include reduced time to market, better quality, increased productivity, customer satisfaction and profitability. iBaan is an integrated web based tool that helps better visualization of companies' internal and external supply chains.

Baan supports both discrete and repetitive manufacturing systems and provides the manufacturers with flexible enterprise planning tools. Baan's manufacturing solution with its advanced manufacturing execution systems (MES) provides integration of planning and shop floor systems at each level across various sites, thereby allowing continuous monitoring of the production status and enabling the management to respond to customer changes. The advantages of integrating ERP and MES in Baan's automotive solution are:

- Increase in plant throughput with lead time, work in process (WIP), cycle times and reduction in defects
- Reduction in machine downtimes and production halts
- Reduction in reworks
- Improved quality and on time delivery

The iBaan software is made up of many business tools to effectively integrate and collaborate the traditional enterprise with internet-based systems. The various business tools of iBaan are listed.

- Procurement ⇔ iBaan E-procurement
- Enterprise resource planning ⇔ iBaan Enterprise with AGS
- Collaboration ⇔ iBaanB2B server
- Manufacturing execution ⇔ In track
- Product lifecycle management ⇔ iBaan PDM
- Information, management, reporting and analysis

All these business tools developed by Baan work for total integration of the manufacturing systems, supply chain management systems and customers with Internet, and are being successfully implemented in many industries such as automobile, aerospace, electronics and industrial machinery and equipment.

iBaan PDM connects design and engineering together and tries to bridge the gap between design and manufacturing processes. iBaan takes care of the design and engineering activities by standardizing design and engineering processes, linking the CAD data and interfacing with the enterprise management [8].

2.1.2 Peoplesoft

Peoplesoft enterprise solutions integrate and consolidate complex operations into a single computing environment and reduce the resource overhead by sharing a single data source. People soft cater to various market needs providing industry specific solutions to customers in financial services, healthcare, manufacturing, public sector and US federal government. All customer needs are addressed by Peoplesoft through its various products, including the following:

- Peoplesoft Financials
- Peoplesoft Manufacturing
- Peoplesoft HRMS
- Peoplesoft Distribution

Peoplesoft Manufacturing caters to the needs of continuously changing informational needs of various manufacturing systems such as assemble-to-order, make-to-order, make-to-stock, repetitive or mixed mode. Peoplesoft manufacturing has the following applications: production planning, engineering, bills and routings, production management and cost management [9].

2.1.3 SAP

SAP is one of the market leaders in supply chain management and ERP software systems. The mySAP module provides various solutions for the industry including supply-chain management, enterprise resource planning, supplier relations, and product life cycle management. The mySAP ERP leverages existing IT assets and also regains active control of administration and operations environment, ultimately increasing efficiency and profitability. Based on the need the customer can upgrade to any of the full range of SAP solutions to include the necessary functionality. The Supply chain management module in mySAP provides seamlessly connecting supply, planning, and manufacturing and distribution operations in the organisation [10].

Other ERP/MRP/SCM packages available include packages available from Industrial and Financial Systems (IFS), JD Edwards (merging with Peoplesoft), Kewill, Lawson Software, and Oracle.

2.2 Software tools for CAD/CAM

Following is a representative sample of available CAD/CAM software solutions, and recommended hardware configurations. It must be noted that hardware and software advances of the last few years are constant; consult the latest technical manuals for your particular solution. The number of available software packages is significant, and will continue to grow as specialized applications are developed.

2.2.1 Mastercam

Mastercam can operate on windows 3.1, Windows 95 and/or Windows NT with Intel compatible PCs only. Intel Pentium 4 offers the hyper threading technology that allows the processor to execute two threads simultaneously so that the software runs efficiently. This allows for effective multitasking. The Pentium 4 comes with an 800 MHz system bus and speeds ranging from 2.4 to 3 GHz. A 256 MB RAM is sufficient but to increase the efficiency a 512 MB RAM is recommended. A 250 MB hard disk with a hard drive of 7,200 rpm is required for loading the software and out of which 200 MB is free after installing. A 64 MB video card with hardware 3D accelerator and open GL support is recommended.

Mastercam runs on Windows 3.1, Windows 95, and on Windows NT with Intel compatible PCs only.

Operating System: Windows 2000, NT4 (SP5 or higher), 98 or ME
CPU: Pentium Based, recommend 266 MHz or faster
RAM: 256 MB is sufficient but 512 MB or more recommended
Hard Disk: 250 MB to load, min. 200 MB free after installation
Video Card: 64 MB card (or more) with hardware 3D acceleration and solid OpenGL support.
Hard Drive: 7,200 rpm UDMA 100/133 IDE or Wide Ultra2 SCSI
Graphics: Windows Accelerator with OpenGL capabilities. With AGP, minimum of 8 MB of RAM, with PCI minimum of 16 MB. MCAM recommends you run at 1024×768 16-bit colour (NOT 32 BIT HIGH COLOR), with the very latest video drivers available. Confirm this resolution/depth works, before experimenting with higher resolution/depth settings [11].

The latest hardware configurations for Mastercam and Cadkey recommended by CADWIRE, a Canada based company that regularly tests and benchmarks new hardware that is compatible with new versions of the latest software is given overleaf in Table 2.

2.2.2 Surfcam

The minimum hardware requirement necessary for running Surfcam is a Pentium 2 processor with 200 MHz or higher, and 64 MB of RAM. It can run on Windows NT 4.0, Windows 2000 or XP. Any basic graphic card can be used.

The minimum RAM requirements vary with the functionality. For example, for design and 2-axis machining a 64 MB ram is sufficient, but for 3-5 axis single- and multiple-axis machining with files up to 750 surfaces and more, at least 128 MB is needed. Table 3 gives minimum, recommended and optimal hardware specifications recommended by Surfcam, and Table 4 lists the optimum RAM specifications [12].

Table 2: Hardware configurations for Mastercam and Cadkey.

CPU	Intel 2.4 GHz Socket 478 512K Cache
Memory	512 MB PC2700 333 MHz DDR 64X64 184 Pin DIMM
Hard Disk Drive	Western Digital 40GB 8M Cache UATA100 7200RPM
Motherboard	Intel D845GEBV2L S478 ATX, DDR
Optical Storage	CD-ROM AOpen 956 56X UDMA
Video Card	GeForce4 Ti4200 128 MB RAM DDR
Keyboard	Microsoft Multimedia Keyboard & Wheel Optical Mouse
Mouse	Logitech O35 Optical Mouse (Optional Cordless)
Removable Storage	Panasonic 1.44 MB Floppy Drive
Case/Power Supply	AOpen QF50C Mid Tower case with 300W Power Supply
Operating System	Windows2000 or Windows XP Home/Professional

Table 3: Minimum, recommended and optimal hardware specifications for Surfcam.

Requirements	**Minimum**	**Recommended**	**Optimal**
Processor	Pent II class CPU 200 MHz or higher	Pent III class CPU 1 GHz or higher	Pent III class CPU 3 GHz or higher
Operating System	Windows NT 4.0 (SP6)	Windows 2000 or XP	Windows 2000 or XP
Ram	64 MB	512 MB	1 GB
Graphics Card	Basic	OpenGL Graphics Card	Mid to Upper level OpenGL Card

Table 4: RAM specifications for Surfcam.

RAM Requirements	Minimum	Recomme nded	Optimal
Design and 2-axis machining	64 MB	128 MB	256 MB
3-5-axis single and multiple surface machining with files up to 750 surfaces	128 MB	256 MB	512 MB
3-5-axis multiple surface machining with files more than 750 surfaces	128 MB	512 MB	1 GB

2.2.3 Work NC and Step-NC

The hardware specifications for Work NC are Windows 2000 Pro/XP Pro, RAM 256 MB or more, mouse with roller wheel and open GL graphics card [13].

STEP-NC aims to make the CNC controller to achieve an autonomous control function to understand the language used in upper level manufacturing functions, define what, why, and how to machine on its own, and to execute and control the machining work, as well as a smart interface function to directly communicate with upper manufacturing functions such as CAD-CAM-CNC.

The Step and Step-NC information highway is real time application of this technology in large manufacturing companies. The CAD systems of these manufacturing giants are coupled with the help Step Interface and these are in turn coupled to their suppliers with Step-NC interface, which perform a variety of applications such as Cam, CAPP, NC Milling and NC turning. The Step-NC interface is Step and database on the Internet, which allows CNC controllers to directly communicate with CAD/CAPP/CAM/CNC.

3 Hardware

Hardware requirements for E-manufacturing systems are often divided into the following categories. A summary of the hardware is given in Table 5. More detailed discussions are given afterwards.

Table 5: Hardware summary for e-manufacturing

Category		Product	Vendors	Website
CAD/CAM Hardware Integration	CNC	(1) Ion Interface (2) Cortex Gateway (3) Behind the tape reader interface	e-Manufacturing Networks Inc	www.e-manufacturing.com
	PLC	PLC-5	Allen-Bradley	www.ab.com
	Encoders	845G Absolute Encoder	Allen-Bradley	www.ab.com
		845H Incremental Encoder		
Remote Monitoring Equipment	Wireless devices	Barcode scanners Wireless LAN's PDA/Palmtops Mobile PCs	Mass Group Mass Group	www.massgroup.com www.massgroup.com
Database Management components				
Components for integrating with web/Internet		Access points	Cisco	www.cisco.com

- CAD/CAM Integration Hardware

(1) CAD Graphical User Interfaces (GUI)
(2) CAM Interfaces
(3) Programmable logic controllers

(4) Encoders and drives for feedback
(5) Motion controller boards

- Data management components

(1) Database Servers
(2) Computers
(3) Raw storage (Disks)

- Remote monitoring Equipment

(1) Monitoring Screens
(2) Video/Camera

(3) Wireless Handsets
(4) Palmtops
(5) Pagers

- Network technology

3.1 CAD/CAM integration hardware

One of the most important pieces of hardware for use in the integration of CAD and CAM is the programmable logic controller that controls machines, the graphics displays that allow the user to view the creation of the parts, and the interconnection of shop hardware with computer hardware. Other devices that are important to operation, but not directly related to computer infrastructure, are the various sensors and monitors available to supervise machine operation.

3.1.1 Programmable logic controllers

A PLC acts as a simple computer - waiting for inputs and sending out outputs. Programming a PLC is relatively simple - many of today's PLC programming software is icon driven - meaning you drag and drop graphical pictures of the switches and sensors and put them in a flow chart type of organization.

A PLC program for a large manufacturing line may contain hundreds of sensors, motor starters, and switches, and might have thousands of lines of code able to run the full production automatically - but, as shown here, integrating a small PLC to begin automating a section of a machine is relatively simple. And one of the useful features of many controllers is that they are expandable [14].

The latest generation of PLCs integrates Ethernet components directly on the board and includes an integrated web server on each PLC, from which the PLC can be configured and managed. The controller unit can communicate with many different network topologies and technologies, including Ethernet (10Base2, 10Base5, 10BaseT), Serial (RS-232, RS-422, RS-423A), Universal Remote Input/Output, and proprietary technologies such as DeviceNet, ControlNet, and Data Highway Plus (DH+). They maintain the following specifications for their various classes of PLCs [15]:

- Maximum User Memory: 8 K – 100 K
- Total I/O: 512 K – 6144 K
- Maximum Channels: 1 – 4 DH+/ remote I/O

Additional modules can be added to these controllers, adding the functionality of Ethernet and other proprietary technology into the PLC. If Ethernet is added as an option, all of the varieties of Ethernet cabling compatible with these PLCs run at a maximum bandwidth of 10 MBps.

3.1.2 Graphics terminals, displays, and monitors

One of the earliest challenges to computer developers in the early 1950's was the interface between man and machine. In using computers to design and engineer parts, a rendering of the part as an image was needed to facilitate design and manipulation. The development of displays has come a long way from the first display systems; the history of these graphical display units can be broken into four general eras:

(1) Direct-beam refresh
(2) Direct-view storage tubes
(3) Raster scan
(4) Digital liquid crystal display

The earliest direct-beam refresh monitor was developed through a joint effort between the US Air Force and MIT. Project SAGE used a computer to display the location of Russian airplane targets, taken from information provided by radar. The method was slow because the operator had to manually direct an interceptor to assess the target. These early directed-beam refresh systems refreshed the image by shooting a beam of electrons at the phosphors of the CRT tube several times per second. Because of speed limitations, a screen with a lot of text or images on it (high-density image) flickered. Early models were very expensive, and a cheaper method of displaying images was sought. Figure 5 represents one of the early display devices.

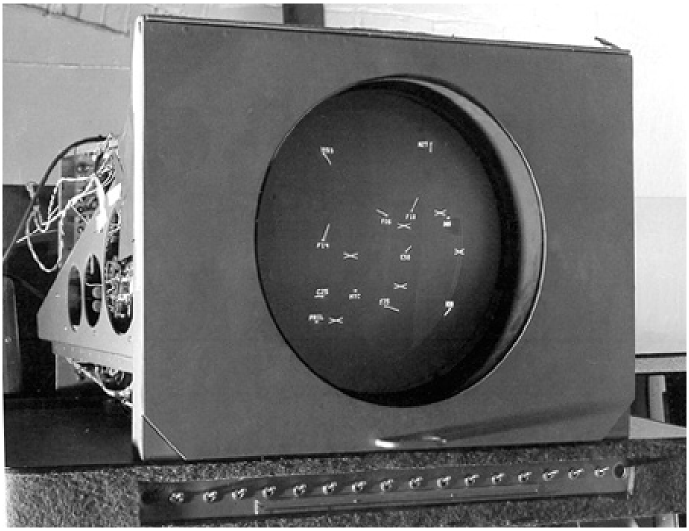

Figure 5: Circa 1952—Close-up of SAGE system digital display scope. Display tracked both intruding and interceptor aircraft (Photo Courtesy: MITRE Corporation).

Direct-view storage tubes (DVST) composed the second generation of graphical display devices. Developed in the mid-1960's, these tubes could adequately display high-density images, and the display stored the image once it was drawn, eliminating the need to constantly refresh it. Image quality was not as good as directed-beam models, but the DVST eliminated image flicker. The first tube was manufactured by B.B&N Corp. as a five-inch model. Six- and eight-inch models by Tektronix replaced it quickly. The main disadvantage was that while the image could have lines added, to remove a line the whole screen had to be refreshed, and also that colour was not an option for DVST systems.

The next generation of displays is the raster refresh method, still commonly used in many modern displays. The raster refresh method creates a matrix of picture elements (pixels) that represent the screen image. The electron beam covers one line at a time, after which it moves to the next line. Modern interlaced raster displays will paint every other line, and then return to refresh the lines in between. Such a display makes the response time appear faster to the end user. The main detraction to early raster systems was the high cost of memory; each screen had to be written to a memory buffer, and then printed to the screen. The light pen was used as the input device for interactive computer graphics. Figure 6 shows the use of a light pen to target potential intercept co-ordinates.

Figure 6: Circa 1959—Operator uses special light gun to target potential intercept coordinates (Photo Courtesy: MITRE Corporation).

Look at the memory requirements for a monochrome system, where a pixel is either on or off: 640×480 resolution. In the 1960's and 1970's, memory was very expensive (≥ $1,000,000/Mbyte) so there were few raster scan systems [16].

As memory costs have been greatly reduced (a common computer graphics card can be found with memory less than $1/MByte), [17] raster systems have grown in popularity. Additionally, raster displays allow a wide range of colours through variation of beam voltage intensity [16]. While raster displays on CRT tubes are still in wide use throughout the world, they are quickly giving way to liquid crystal displays (LCDs) because of the LCD's smaller footprint.

Liquid crystal displays represent the fourth generation of display technology. LCDs are based on the principle of filtering white light through a series of filters. A current can be passed through the filter layer, allowing varying amounts of light through each layer. LCD screens are much thinner and lighter than CRT monitors (Sony 23 inch LCD SDM-P232W/B 38.3 lbs vs. 24 inch CRT GDM-FW900 92.6 lbs) [18]. The main drawbacks of LCD technology are the increased cost and decreased brightness and useful life [19]. Resolutions are typically higher for LCD than CRT displays; it is common for native resolutions of 1,024×768 for 17-inch displays and 1,280×1024 or 1,600×1,200 for 18-inch displays.

3.2 CAM interfaces

Perhaps the most important step in automating and integrating the manufacturing process is the physical machinery on the shop floor and its ability to receive instructions from the operators, to communicate to the computer system, and to communicate with other machines.

In order to integrate this hardware into a computer-managed system, each of the machines must provide Input/Output (I/O) ports to the network. The most common of these solutions is connection through inexpensive Ethernet (RJ-45) connections. Some older machines with only serial ports can be retrofitted with Ethernet connectors. In distributed environments, wireless communication is emerging as a viable option [20]. Some of the most commonly used CAM hardware is introduced below.

3.3 Ion universal interface

The ion universal interface is an embedded device that turns CNC into a web server that contains vital information required for shop floor control. This device sets up two-way communication with any existing CNC using standard application protocols such as HTTP, FTP and SNMP over TCP/IP. The ion interface connects CNC to the Ethernet network, and allows fast and accurate data transfer to the machine tool. It also provides necessary shop floor metrics such as job status, productivity, machine downtimes and alarm conditions. The Ion universal interface supports various communication standards in order to interface the data collection with existing software applications like ERP, MES, CRM, etc. The historical data can be directly accessed using OPC standard or can be sorted to an SQL database [21].

3.4 Cortex gateway

The Cortex Gateway allows connection to various CNC to obtain shop floor information and to provide this information to application software such as ERP/SCM/CRM/MES. The Cortex Gateway connects a number of ion universal interface devices to a single point thereby providing a gateway to the corporate network. To allow secure access to manufacturing from any browser worldwide Internet can be connected to the CNC. Cortex receives the data from the ion interface and stores them in an SQL database [21].

3.5 BTR-behind the tape reader interface for NC/CNC machine tools

The Memex Mx1000 BTR is a micro controller-based serial interface board that can replace paper tape readers found on older NC and CNC machines. The bi-directional serial interface can access with any computers outside the world and allows for loading and executing of part programs from any serial source. It can emulate Fanuc, GE, Remex, Eeco, Decitek and Sanyo Denki tape readers without disabling the host tape readers. The Eavesdrop mode enables back up of punch tapes on the computer and it can convert these tapes into a disk while it's running. The Mx1000 is easy to install and does not require skilled personnel for installing it. It is compatible with a number of terminal software platforms such as Spectrum Multi–DNC, Facit NC, Procomm and a number of other CAD/CAM DNC packages [21].

4 Data management components

Modern manufacturing has begun to implement a system whereby product information can be stored in data files. This data can be used to order components on demand, sending the data directly to the CNC tools, reducing transition times and waste. Complex components have associated with them large files. The conversion to a computer-based, paperless office does not eliminate the need to keep records, though. In addition to these advances in manufacturing, instrument documentation, interoffice memorandums, electronic messages, and a variety of other documents need to be stored digitally. As the amount of data stored on corporate networks increases exponentially, so too does the need to physically house the data. Two methods have emerged as solutions to the need for storage: disk-to-disk and tape storage.

4.1 Disk-to-disk

Disk-to-disk storage is similar to your computer's hard disk. Data is kept on file servers that are available in real-time. Networks of this type are emerging as Storage Area Networks (SANs). SANs are capable of storing large volumes of data. For example, Sun's StorEdge 9960 is scalable to maintain 92.7 terabytes of data. Systems can be clustered to increase data storage capabilities. Smaller companies can take advantage of smaller capacity solutions such as IBM's TotalStorage 200i model with as little as 109 GB of storage. These solutions include bundled software to manage data on the network.

4.2 Tape

Nearline storage is provided by tape backup systems for data storage. Nearline means that the data is not instantly accessible, but can be restored from compressed data stored on magnetic tape. Nearline systems are usually used for backup purposes. Tape libraries are available that hold multiple tapes and a mechanism for switching automatically between tapes. Models such as IBM's TotalStorage LTO Ultrium Ultrascalable Tape Library 3584 can hold up to 992 TB of compressed data. Software and hardware configurations are available for clients to directly backup their work, or to backup from disks in a SAN.

Major competitors in the storage area are HP, Sun, IBM, and EMC. Figures 7, 8 and 9 are representative products in the area of storage.

Figure 7: IBM TotalStorage Fast T900 storage server (Photo Courtesy: IBM).

Figure 8: IBM TotalStorage LTO Ultrium Ultrascalable Tape Library 3584 (Photo Courtesy: IBM).

Figure 9: EMC CLARiiON CX200 (Photo Courtesy: EMC).

5 Networking

Networks have developed a great deal from the earliest technologies. Since the first network of computers was created (ARPANET) in 1969 [19], computer networks have grown in popularity while the speed of data transmissions has increased. Latest technologies in networking protocols have allowed wireless fidelity (WiFi) and fiber-optic networking to be developed. In 1992, Fluker stated: "Only a few years ago 300 baud was 'speedy' and multi-second response times were considered acceptable. Today we have progressed from the 300 baud, point-to-point, connectivity to networks which support mega-bit data transfer rates and response times measured in milliseconds through a manufacturing facility [20]."

In the years that have followed, network speeds have dramatically increased. Typical interoffice LAN's allow speeds of 100 Mbits/sec and advanced LAN's support 1 or 10 Gbit/sec data throughput. The networking topology of choice has evolved to Ethernet, with either RJ-45 connectors or, in recent developments, wireless interfaces.

5.1 Local area networks (LAN)

Several hardware devices exist to create an infrastructure for an office LAN.

5.1.1 Hub

A hub connects two or more networked devices. Typical hubs operate at 10 or 100 Mbits/sec. All devices connected to a hub share a bandwidth, so a 5-port 10 Mbit hub with all ports in use could expect only 2 Mbit bandwidth per port. Because this is split between I/O, the hub really experiences only 1 Mbit/sec of realized bandwidth.

5.1.2 Switch

A switch has the same basic function as a hub, but allows all ports equal bandwidth. Switches have circuit boards that can route data packets and minimize data collisions that result in data loss. Full-duplex switches allow twice the bandwidth by maintaining full speed for incoming and outgoing connections. Switches are typically 10 or 100 Mbits/sec, but some Gigabit (1 Gbit/sec) switches are manufactured by leading vendors.

5.1.3 Router

A router connects two LANs together, or connects a LAN to a WAN. Routers house complex electronics that allow for Network Address Translation (NAT). NAT makes it possible for two LANs behind separate routers to use the same IP address without causing addressing conflicts. The router identifies incoming data packets and sends them to the appropriate machine.

5.1.4 Print server

Print servers are specialized devices that receive print requests from machines on the network, and place them in a queue for the printer. Print servers have Random Access Memory (RAM) chips that store the data until the printer is prepared to spool the document.

5.1.5 Virtual private networking (VPN)

A VPN allows remote users to access a LAN as if they were located on-site. VPN devices are special pieces of hardware that encode and decode data that is passed over the public Internet, encrypting it to keep it secure from undesired eyes.

5.2 Wireless fidelity (WiFi) LAN

The wireless local area network (WLAN) allows flexible data transmission without the need for wiring the entire building or a factory. The WLAN transmits and receives data using radio waves, ultimately eliminating the need to wire the entire local area network and reducing the cable installation costs. Common implementation of wireless LANs is in the use of IEEE 802.11b standard (11 Mbit/sec), but the speed of connection depends on the number of active users and also presence of walls, ceilings, etc. In addition to the 802.11b standard, the IEEE has approved standards for 802.11a and 802.11g. These specifications allow for transmission speeds of 54 Mbit/sec, with the "a" standard having a greater range and the "g" standard offering the best compatibility with existing "b" equipment. WiFi networks require their own specialized hardware.

5.2.1 Wireless access point (WAP)

A WAP is a centralized transmitter/receiver that communicates data to and from wireless network adapters within a range of 100–500 feet. This range depends on the type of antenna in use, the 802.11x standard, and other physical configuration variables. In order to increase this working range/perimeter, multiple access points are added. The access points create cells and the user can roam from one cell to another without getting disconnected from the LAN.

5.2.2 Wireless network interface cards (WiFi NIC)

A WiFi NIC is used to connect a computer to the wireless LAN. Each computer needs its own NIC in order to communicate with the network. The speed of transmission is limited by the proximity of an Access Point and the IEEE standard in use. They are available as PCI cards for desktop computers, PCMCIA cards for laptops, and also with USB ports for connectivity to any machine with a USB port. NICs can also communicate peer-to-peer using the Ad-hoc mode.

5.2.3 Wireless bridge

A bridge is a device for connecting wired devices to the WLAN. In a manufacturing shop, it is likely that the machine tools will first be wired to Ethernet connections before wireless connectivity is achieved. To connect these machines to the WLAN, a bridge is connected to the hub or switch, and then all machines plugged into the hub will have wireless access. Data speeds between the wired components are limited to the bandwidth of the hub or switch (10 or 100 Mbit/sec), and wireless speed is determined by proximity of a WAP.

5.2.4 Directional antennas

Directional antennas are used to increase the perimeter or coverage area of the network to inaccessible points. These antennas have a directed rather than an omni-directional radiation pattern. These antennas provide seamless data transfer, creating a bridge from building to building, connecting various access points. These antennas are available in two different configurations; point-to-point and point-transmission to multi-point transmission (omni-directional). Depending on the application, the range of the antennas can vary from 8 miles to 23 miles or more.

WiFi equipment has grown progressively cheaper and is very accessible to most small companies. The largest perceived problem with WiFi is security. The Wired Equivalency Protocol (WEP), a 128-bit encryption scheme that was supposed to provide the same security as traditional networks, was shown to be easily broken. Companies that utilize wireless technology should keep this in mind if using the WLAN to transmit important information.

5.3 Pocket PC or mobile computers

The shop floor data can be directly reported to the managers using wireless technology. A pocket PC is the most widely used tool in an industry where product related information could be shared among different people working on the product from different dispersed locations.

5.3.1 Intermec 700 Series wireless colour mobile computer

Intermec 700 Series Wireless Colour Mobile Computer is a product by Mass Group, operates on Microsoft windows 2002 for pocket PC platform, with a 400 MHz, Intel Xscale PXA250 application processor. A RAM of 64 MB is sufficient and an optional 128 MB can be used and a 32 MB Flash ROM with an application storage folder is available. It has integrated radio options with a LAN (802.11b) and WAN (blue tooth compatible). The pocket PC can be connected to the Internet with a V.90 modem that snaps onto a landline modem. Alerts can be emailed to service personnel enabling them to continuously monitor shop floor data and helps online decision-making to be simplified.

5.3.2 PSC barcode scanners

Power scan RF is a wireless scanner that utilizes the latest in radio frequency technology to scan. The advantage of wireless scanners over traditional restricted cable scanners is that the product to be scanned need not be brought to the base station; instead the scanner can go to where the work is. The wireless scanner has a working range up to 150 feet from the base station. It also offers multi-point operation with up to 8 scans from a single base station. Major applications of the wireless scanner include inventory management, warehousing, shipping and receiving.

6 Implementation

The impact of e-manufacturing has begun shifting from the traditional "factory integration" philosophy to a "virtual factory" management philosophy. The technological advances for achieving this highly collaborative design and manufacturing environment is engineering tools and a highly reliable communications system for concentrating distributed procedures in concurrent engineering design, remote operation of manufacturing processes, and operation of distributed production systems.

Figure 10 shows a simplified model of an industrial enterprise and its main functional units. In this system, CAD, CAPP (computer-aided process planning) and CAM software for the products are built and loaded on some of the distributed servers, which are accessible and executable, by remote users anywhere on the Internet. A user can first use the CAD system to design the product, then calls up the CAPP system, which may be available on a different server, for process planning and route sheet preparation. The Part Family system, which is a collection of parts that are similar either in geometric shape, size or in processing steps required for their manufacture, can also be called up during the CAD and CAPP processes.

Finally, the files generated by CAD and CAPP systems are transferred to the CAM system at an appropriate location where actual manufacturing takes place through the local CNC monitoring and control center. There are also two databases in INS. The Common Database (CS) contains information about commonly used work and tool materials with their properties, static and dynamic performances of machine tools, jigs and fixtures, etc., needed for the CAPP. The Research Database (RB), on the other hand, has standard models for calculating parameters like cutting forces, torque, heat generation, deformation layer, etc., for the engineering analysis of the design. With the use of the two databases, the time-consuming new product design period, planning period, and even the research period will be reduced to a minimum.

The main operations in e-manufacturing start at product planning, with methodologies for finding and conceiving future oriented products, which extend to development/design (CAD) and manufacturing process planning (CAP). It concludes with control of automated manufacturing systems (CAM), in particular with concepts of new automation strategies. This process chain is commonly described by the term CAD/CAM.

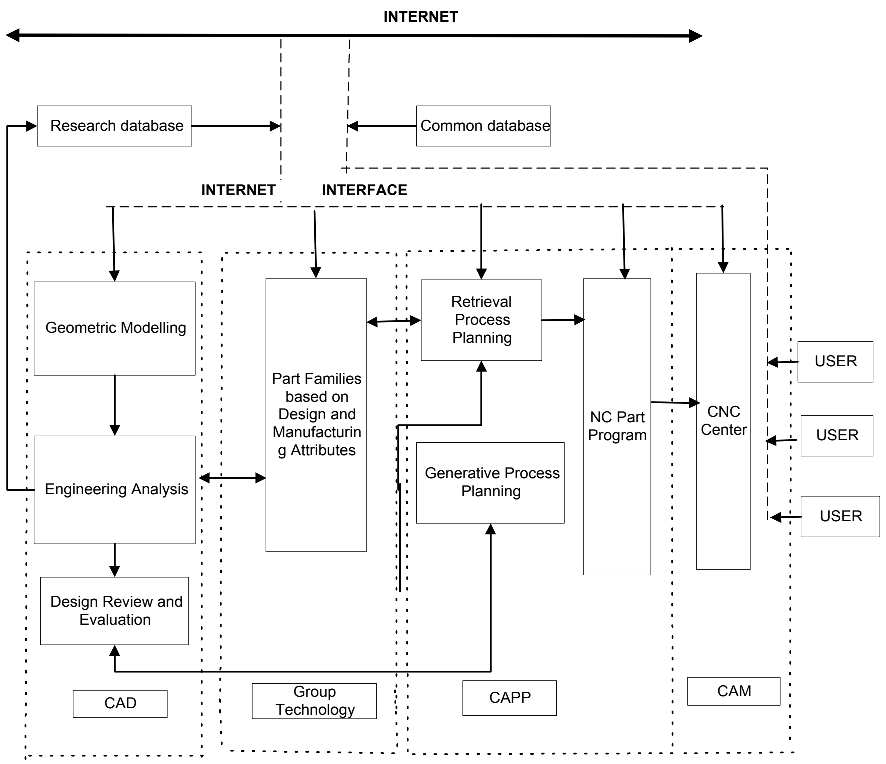

Figure 10: An illustration of the Internet-based network system.

Next step in e-manufacturing is to integrate this CAD/CAM process chain with the top floor management of the enterprise using the software and hardware tools described above. The integration of the shop floor with the top floor is traditionally considered as the weakest link in the enterprise, but with increasing developments in the hardware technologies and software tools this gap is being bridged to a major extent. The successful implementation of e-manufacturing can be achieved by seamless integration of the CAD/CAM process chain with MRP/ERP/SCM/CRM.

The implementation framework of computing infrastructures for e-manufacturing is based on the hardware and software requirements for integrating CAD/CAM, ERP, MRP, SCM, and CRM. These requirements are listed in the two charts in the software and hardware sections of this paper. The complete integration of the enterprise with design, plant floor, supply chain, MRP, and CRM using the Internet can be considered as a successful implementation of e-manufacturing.

The basic architecture of e-manufacturing integrates various modules of the enterprise using the software and hardware components discussed in the previous section. The various modules that are to be integrated are product and manufacturing engineering, plant monitoring and control, sensing real time data and remote monitoring and control. The real time data for the product and manufacturing is supplied by planning, design, ERP, PDM and CRM. Figure 11 shows the model of the e-manufacturing architecture proposed by Intelligent Maintenance Systems (IMS) [21]. This model highlights the challenges of working with the real time data in an enterprise.

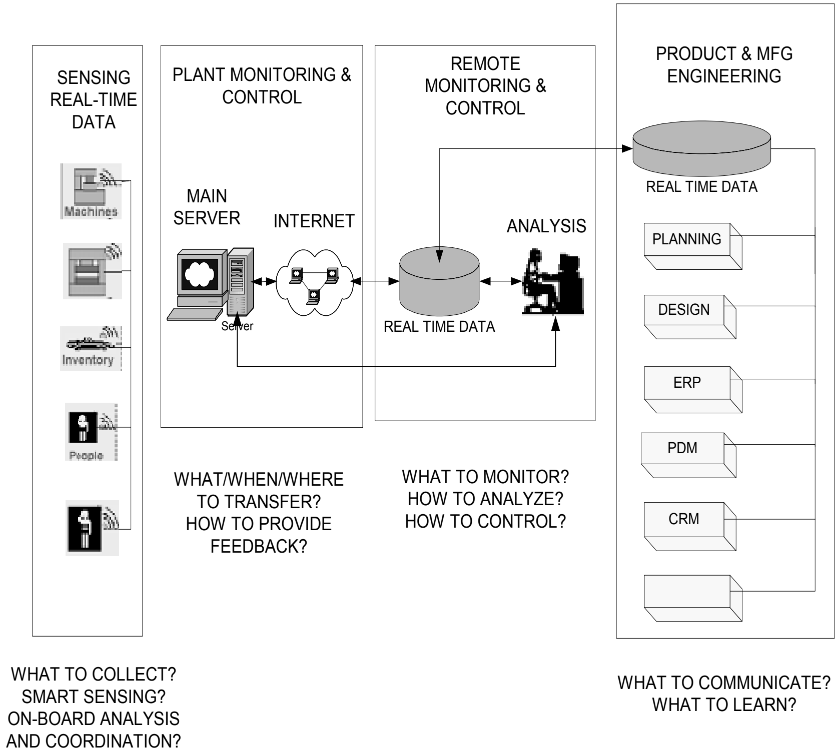

Figure 11: The e-manufacturing architecture (Courtesy: Intelligent Maintenance Systems, Milwaukee, Wisconsin).

The implementation of this architecture, based on the software and hardware components discussed above, is presented in a brief manner. The integration of the plant monitoring and control module requires a computing infrastructure that can effectively take care of the following components: Design, ERP, SCM and CRM. The hardware and software for these components have been discussed earlier. Currently available ERP software such as Baan, SAP and Peoplesoft to a major extent integrates the top floor management with the shop floor enabling fast and accurate information flow. Software for acquiring the real time data about numerous processes in the enterprise is being developed to meet the new challenges and to provide better customer service. The use of open standards by the software providers makes the software upgrade an easy task as the hardware required will remain the same in many cases, thereby saving the cost of installation and rewiring.

The computing infrastructure for implementing remote monitoring and control module in the e-manufacturing architecture requires hardware and software for wireless technology and the devices for implementing local area networks (LAN). The wireless equipment includes palm tops, pocket PC or mini computers, etc., that provide the real time data from the shop floor to the top floor management.

Following these notes on issues surrounding implementation are case studies of companies that have implemented these systems to support the e-manufacturing future.

6.1 Implementing CAD/CAM

The software that is used for integrating CAD with CAM must be compatible with both, allowing data transfer between the two to be invisible to the user. They should be able to transfer the CAD data as input to CAM machines; hence a standard format like Initial Graphics Exchange Specification (IGES), Standard for the exchange of product model data (STEP), PARASOLLID, etc., is essential for this purpose. Each of these specifications uses a particular data format to define the geometry of a part. Most CAD software such as Pro/E, AutoCAD, SolidWorks, Unigraphics, Catia and Ideas support these standard formats. These programs also have utilities for converting this data into G-codes and M-codes that are used by CNC machines to produce a part. CAM systems take the input from the CAD files and generate the tool path based on the design. An additional feature known as Automatic Feature Recognition (AFR) is under development; this feature allows a user to import a solid model from a modelling software program and automatically update tool paths for creation of the part [22].

6.2 Implementing ERP/MRP/SCM

By integrating ERP/MRP/SCM software with real-time shop-floor data, managers can better visualize all parameters affecting efficient operation, including inventory, production, machine maintenance, and others. By effectively managing resources and supply chain, productivity can be increased and significant cost savings can be achieved.

Each of the ERP/MRP/SCM vendors develops recommended hardware configurations based on customer needs, existing hardware infrastructure, and future expandability.

7 Case studies

7.1 Britax

Britax, an aircraft interior supplier, is a successful example of using Baan to provide enterprise application solutions to discrete manufacturers in the field of aerospace, automotive, industrial machinery and equipment, electronics and defence sectors. In order to meet the changing demands of the industry and to remain competitive in the business, Britax was looking for an enterprise resource system that allowed them to better monitor, improve and control the production right from materials coming in, and progressing to final delivery. According to Britax, Baan offered them more flexibility and better capability to adapt to their changing business.

The computing infrastructure used by Britax was iBaan's enterprise solution, iBaan DEM; the hardware was from Hewlett–Packard utilizing Unix in its operating system. The database is from Informix. Within a short time of implementing iBaan the company increased its on-time delivery rates from 65% to 98%, and now it is maintained even higher, at 99%. The productivity increased by 20% and the inventory reduced by about 20% resulting in huge cost savings [23].

7.2 Corning

Corning is the manufacturer of a diverse field of products, including glass kitchenware, precision glass lenses, optical fibers, and a host of other products, for an international market. Addressing their computing needs across the enterprise, they sought a system that fitted their niche as an OEM, a supplier, a customer service organization, a sales organization, and a technology innovator. To fill this need, they incorporated modules from Peoplesoft, including human resources, finance, procurement, and supply chain management. Manufacturing and engineering modules were employed where necessary within the manufacturing environment. Doug Anderson, Corning's CIO over Speciality Materials says, "We're constantly working on yield and cycle times. By having this improved information infrastructure in place, our reaction time will improve significantly" [24].

7.3 Westcoast Performance

Westcoast Performance is a supplier to the automobile industry. It machines high performance 400 in^3 push-rod V-8 engine blocks for Ford and Nissan, intake manifolds and water pumps for Chrysler, chassis for Mission Roller Hockey, and exhaust systems and intake grates for Bombardier's Sea-Doo personal watercraft. The CNC programming department was asked to machine moulds for use on the Sea-Doo personal watercraft. The CAD wire frame and surface model was designed in Pro-E and imported to Mastercam through the IGES format; the required tool path was then generated with ease through Mastercam's code generation utility. Having the software automatically create this coded file shortened the waiting time between steps [25].

7.4 Sterling Truck Corporation

Sterling is a large manufacturer of custom-built heavy-duty trucks. Each truck order is unique, and the trucks are built to each customer's specifications. Sterling has over 1,000 suppliers, some of them using the same CAD software as Sterling, and others that employ other software with different data formats, such as STEP, IGES, etc.

In order to make sure that all suppliers could interpret the various formats, Sterling developed a program called Data Express. Data Express allows users to upload a file in a certain format, and then uses a mainframe computer on the corporate Intranet to convert the file to another format. The file is stored, and can be converted to other formats at a future time. Because of the time required for data conversion, the system will place the file to be converted into a queue, and notify the user via email when the file is ready.

An innovative approach was necessary to maintain interoperability without replacing the entire computing infrastructure. The system devised met Sterling's goals for CAD interoperability, namely improvements in time, cost, quality, and flexibility. Maintaining interoperability as complexity increases will require constant attention to the computing infrastructure and integration with all steps of ERP in the system [26].

8 Conclusions

The computing infrastructure for e-manufacturing software is evaluated on the following criteria; integration with CAD/CAM/CAPP, integration with ERP/MRP/SCM, and the evaluation criterion for hardware infrastructure includes integration with CAD/CAM, integration with ERP/MRP/SCM and integration with wireless technology. SAP, Baan, Peoplesoft, Oracle, etc., are extensively used software in the industry. Most of this software is built on client–server architecture and this software is modular; consequently, the user has the flexibility to add desired modules as required without major modifications to existing hardware infrastructure. Many of these companies are adopting a web-based design for future products. With all major hardware and software vendors adopting international standards, the task of integrating heterogeneous machines on the shop floor has become very simple. Most software providers and hardware manufacturers give the user flexibility to choose from a range of operating systems, allowing them to pick the one that is best for their enterprise. Common operating systems in use are Windows 95/98/NT/2000/XP, Unix, Solaris and Linux.

Right from the early 1950's, when John Parsons invented the first NC machine, there has been ongoing development in the computing infrastructure in terms of both hardware and software. The NC machines which were capable of only simple point-point motion using programs stored on paper tapes have developed to microprocessor based ones with the capability of downloading programs from anywhere in the world, using the Internet, and providing more complex toolpaths. RJ-45 connections help the CNCs to connect to a company's Ethernet backbone network. The Univac computers used in early days are now replaced with high-speed workstations from IBM and other major companies. The display devices that used to be CRT tubes have developed a lot in terms of resolution and quality. Secondary storage devices serve as backups to the CAD database, and also save the cost of main computer memory. Magnetic disks and tapes are typical secondary storage devices.

Network speeds have greatly increased in a few years, from 300 baud per second, to point-to-point data transfer, and now to megabit data transfers, while the response time has been reduced to milliseconds. With significant advances in network technology the local area networks (LAN's) have achieved a vital role in the manufacturing industry, to collect real time data. Companies have benefited from the ability to access high-speed networks with wireless devices. A range of wireless products is employed in the manufacturing industry that aids the continuous monitoring of the production status, even from remote locations. Wireless remote monitoring devices currently in use in the industry are palmtops, pocket PC's, mobile phones, and pagers.

Finally, with most of the software and hardware vendors adopting open systems interconnection (OSI) as standard, the cost of computing infrastructure for e-manufacturing has come down. In case of any major software upgrades the user need not change the hardware and the cost of installing and rewiring is thus saved. This trend will continue as competition and technology drive down costs.

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