

WEB BASED CIM LABORATORY EXPERIENCE IN ME CURRICULUM: PART DESIGN, NC-CODE GENERATION AND WORK ORDER DISPATCHING VIA INTERNET

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Abstract

This paper focuses on how basic CIM laboratory work can be enhanced through the use of Internet. In the typical CIM laboratory experiment students are asked to produce their NC-Codes for a given task. By the use of the web-site tools as discussed here, students' design their parts, produce NC-Codes, upload them to the FTP-Site and prepare necessary configuration for work-order dispatching. In the lab hour they are again asked to send the work order for the part and watch online status and statistics online. This method demonstrates a typical concurrent engineering approach in an automated manufacturing environment, from design to manufacture.

Keywords: CIM Laboratory, concurrent engineering education, and NC-Code generation.

I.Introduction

The manufacturing industry is going through a period of rapid change, accompanied by record growth. To meet the challenge of selling products into a competitive global economy, while continuously reducing costs, manufacturing companies have to increase the efficiency of existing plants. The organizations are increasingly relying on the new generation of hardware and software systems to achieve this elusive goal. Integration is the key to the success of deploying a modern Computer Integrated Manufacturing (CIM) system, which is an ideal state in which computer based manufacturing applications communicate information to coordinate design, planning and manufacturing processes.

Flexible software has become a major goal for developers of manufacturing automation. Flexibility of machine tools and cells has now reached such a level that it is often the inflexibility of the software, not the machines, which inhibits a fast response to market demands [7]. Major categories of viewpoint to manufacturing automation have grown up from the simplest Programmable Logic Controllers (PLC) to the integration of Computer Aided Design (CAD), and Computer Aided Manufacturing (CAM) in modern manufacturing systems, which define the life-cycle of a concurrent engineering approach. Instead of following the conventional,

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sequentially arranged product development processes, concurrent engineering design incorporates considerations such as manufacturability, serviceability, and recycleability early into design phase [1]. Prasad [5] gives the definition of concurrent engineering as:

“Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through disposal, including quality, cost, schedule and user requirements”.

II. CIM Concepts

Successful application of CIM requires a structured approach. It is important that cell control development should not be too shortsighted by focusing on today's problems, which afterwards may be short-lived [11]. Manufacturing facilities must react to market demands more rapidly, with new products and programs. Additionally, manufacturing companies must be able to dynamically react to changes and reschedule current production needs. Each of these conditions is aimed at increasing throughput, while efforts continue to increase quality and reduce costs [10].

Flexible manufacturing system is a system in which all aspects of CIM are found. FMS is the latest level of automation to achieve more productivity and flexibility from manufacturing equipment. The elements of FMS are easily interchangeable, modifiable PLCs and interconnected hardware, CNC/NC machines usually arranged in cells connected to a computer network. What is called as FMS is simple, an automated manufacturing organization composed of manufacturing elements talking to each other, to perform a specific task [12].

The design of distributed systems of autonomous agents, so called Multi Agent Systems (MASs) for use in manufacturing gained attention in the robotics and automation research community throughout the last few years. Due to their distributed nature, MASs promise, at least theoretically, some advantages that make them attractive structures for control and execution of manufacturing processes. Agents are modular system elements having robustness and fault tolerance and are easily maintainable and extendible. These features of MASs hold the potential of building manufacturing systems with greater flexibility than the currently used monolithic ones [3].

From the programmer's perspective, the concepts of CIM include a broad range of definitions from manufacturing to control/computer technology. Professional software development requires a streamlined process for managing changes in programming technology and networking standards for each application under development [8]. Before building a major application with many separate components, alternatives of Software Development Kits must be reviewed. Programming languages today are usually supplied with necessary user-friendly interfaces and useful help files consisting of large volumes. Object oriented programming languages such as C++, Visual J+, Visual Basic and Web based development kits such as Visual InterDev supporting script-languages of Java (ECMA) script, VB script and database management tools such as SQL-Server, dBase, Oracle etc. are among the ones, which most probably will shape

future developments. The common intersection of commonly accepted programming languages is the object-oriented programming philosophy. The object-oriented programming world consists of objects, which are special entities that can be used to model real world objects, a property known as data abstraction.

Object-oriented design and object-oriented programming represent a change in focus from standard procedural programming. Instead of thinking about program flow from the first line of code to the last line of code, the developer needs to think about creating objects which are self-contained components of an application that have private functionality as well as functionality that can be exposed to the user. The Microsoft's solution to the object-oriented paradigm is represented by Object Linking and Embedding (OLE) components. OLE is a unified environment of object-based services with the capability of both customizing those services and arbitrarily extending the architecture through custom services, with the overall purpose of enabling rich integration between components. In a nutshell, objects are intelligent, self-contained entities responsible for performing particular system tasks [6].

The common interfaces of objects are:

- Properties: Changeable / retrievable features,
- Methods: Actions, functions which are performed by the object,
- Events: External inputs, on which the object is susceptible.

III. METUCIM Laboratory

The flexible manufacturing system at the Mechanical Engineering Department basically consists of a single manufacturing cell. The main material handling system is the closed loop buffer and the 6-axis robot. Also there is a static buffer for loading and unloading parts to the system. The Pneumatic Linear Robot Drive (PLRD) accomplishes the movement of the robot between the CNC Turning- and CNC Milling Machine. Coordinate Measuring Machine (CMM) is the quality control component of the cell. A general view of the system is given in Figure 1.

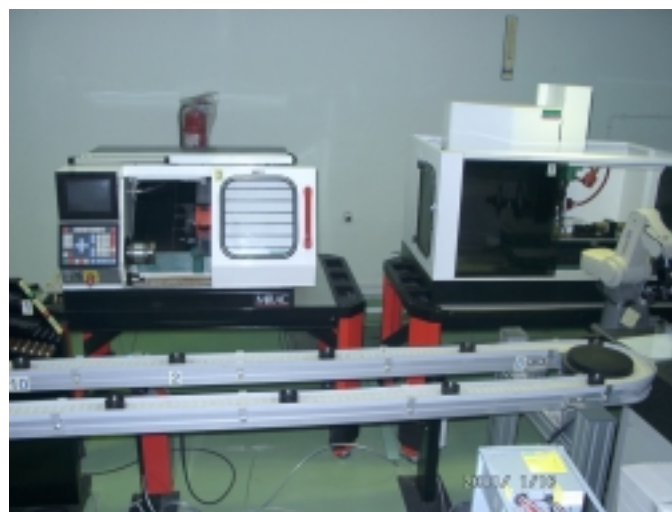


Figure 1 General view of METUCIM

Functionality, properties and capabilities of the manufacturing, transport and quality control hardware can be summarized as:

1. **CNC Turning Machine:** Mirac/Denford/UK. PC based, medium duty lathe having 2 simultaneously controlled axes. Equipped with a turret having 8 stations. Door and chuck are pneumatically powered. Can handle typically bars up to 50 mm in diameter and 150 mm in length, speeds up to 2500 rpm. Has a user-friendly built-in interface to visualize and debug part programs. The control is via standard RS 232 serial communication port and I/O card at a single sensor channel. Channel state OFF indicates that there is no part program running, or the task is finished. Channel state is ON when there is an active program running. “M62” and “M64” codes make the channel ON and OFF respectively.
2. **CNC Milling Machine:** Triac/Denford/UK. PC based, medium duty milling machine-having 3 simultaneously controlled axes. Equipped with an automatic tool magazine with 6 stations. Door, chuck and tool magazines are pneumatically powered. Can handle parts up to 200 mm in width and 500 mm in length, speeds up to 2500 rpm. Has a user-friendly built-in interface to visualize and debug part programs. The control is via standard RS 232 serial communication port and I/O card at a single sensor channel. Channel state OFF indicates that there is no part program running, or the task is finished. Channel state is ON when there is an active program running. “M62” and “M64” codes make the channel ON and OFF respectively.
3. **Coordinate Measuring Machine (CMM):** Kemco/UK. 3 Axis CMM with a table of 600x400 mm wide. Capable of measuring up to 1 μ m resolution and accuracy. The control is accomplished using its own feature based control software running at its host computer. Coupled to the client via the standard RS 232 serial communication port. The client is the part of the agent-based system through Ethernet communication.
4. **Closed Loop Buffer:** SKF/UK. Unidirectional, constant speed, closed loop buffer having 14 cups. Typically, it can handle cylindrical parts up to 50 mm in diameter. Makes a full rotation in 1.5 minutes approximately. Driven by a motor with gearbox. The control is via 48 channel I/O card. Has one operate channel and one counter channel. When the operate channel is ON, it starts to rotate and stops when the channel is OFF, the counter channel is used to count the cups passed.
5. **Robot:** Movemaster EX/Mitsubishi/Japan. 6 axis controlled material handling robot. Capable of handling bars of 50 mm in diameter, weight of 3 kg approximately. The control is by storing positions taught by the user in its EPROM and they can be executed by external triggering of program commands through RS232 connection from the computer. A DSR (data set ready) signal from the serial port indicates that there is no active program running or the task is finished.
6. **Pneumatic Linear Robot Drive (PLRD):** FESTO/Germany. Pneumatically powered linear drive for the robot. Has a movement range of 2m. Has two stop positions at both ends only. In METUCIM configuration it is used to move the robot from CNC Turning to CNC Milling/CMM neighborhood. The control is via 48 channel I/O card. Has two operate- and

two sensor channels. When the first operate channel is triggered and immediately released it moves to right and vice versa for the second. Sensor channels on the left- and right positions indicate ON when the robot is at left and right ends of its range respectively.

7. **Static Buffer (AGV):** Buffer used for in and out loading to the cell. Has 3 input stations which can handle bars of 70-90-100 mm, and 3 output buffers, Accept, Reject and Rework respectively. Is not physically connected or driven by a computer, but as the agent, status information is kept. Although it has no computer control and moving capabilities, it is modeled as an AGV in the system.

In Figure 2, A closer look at the static buffer and CNC Turning machine is shown.



Figure 2 A closer look at the static buffer and CNC Turning machine

Computers are essential parts of the METUCIM. Their properties and functions are summarized as:

1. **Agent PC:** Pentium III 450, 64 MB RAM, 6.2 GB hard disk with 17” monitor. Have 48 channels I/O card installed. Responsible from driving all agents via MSMQ and MTS services and two serial ports. Running under Windows NT 4.0.
2. **Robot Host PC:** 486 DX, 8MB RAM, 3.2 GB hard-disk drive with 14” monitor. Responsible from driving the robot from its serial port, connected to the Agent PC via Ethernet. Receives and sends task status to the agent PC. Running under Windows 95.

3. **CMM Host PC:** 386 DX, 4MB RAM, 600 KB hard disk with 14” monitor. Supports the feature based controller software of CMM. This software is a DOS based program, and very difficult to configure. Connected through the serial port to the CMM Client PC. Running under DOS.
4. **CMM Client PC:** 486 DX, 4MB RAM, 600 KB hard disk with 14” monitor. Supports the feature based controller software of CMM as the client from the serial port. The client PC with the Ethernet connection is used as the agent server. Running under Windows 95.
5. **Backup Controller PC (IIS-SQL Server):** Pentium III 450, 64 MB RAM, 6.2 GB hard disk with 17” monitor. Serves as the backup Enterprise Controller. Internet Information Server, Microsoft Transaction Services (MTS) and Message Queue Services as the main backup and FTP site. Running under Windows NT 4.0.
6. **Primary Controller PC:** Pentium III 450, 64 MB RAM, 6.2 GB hard disk with 17” monitor. The main server of Enterprise Controller, Internet Information Server, Microsoft Transaction Services (MTS) and Message Queue Services. Running under Windows NT 4.0.

A complete layout of METUCIM with the hardware and computers is given in Figure 3.

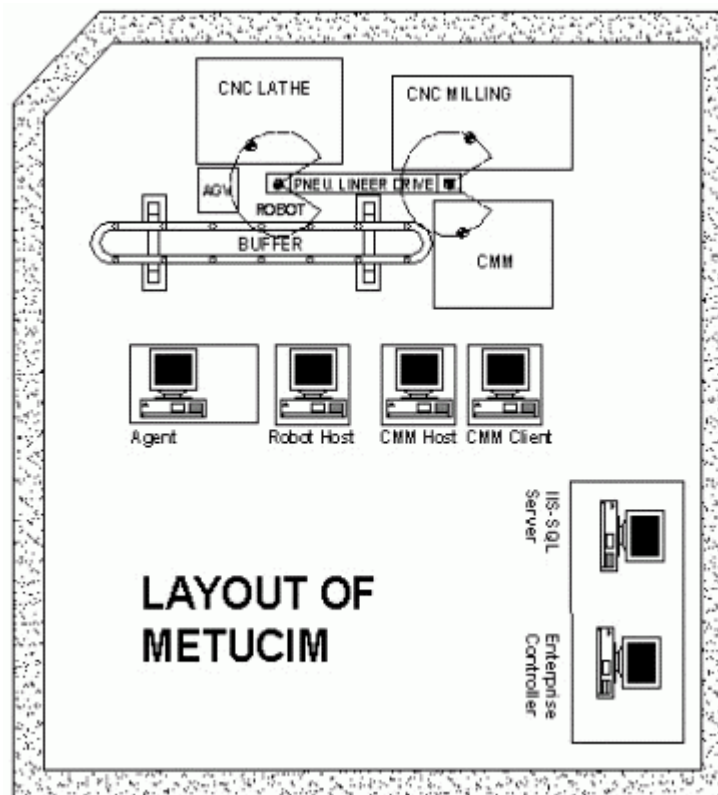


Figure 3 Complete Layout of METUCIM with computers

Also METUCIM laboratory has a Programmable Logic Controller (PLC) drilling and pressing station set for educational purposes, one additional Mitsubishi Movemaster EX robot, and one additional Buffer. This hardware is not related with the work discussed here, so it is beyond the scope.

IV. Developed System

An agent based FMC control model is developed using the three-tiered model of Windows DNA [9]. It has been implemented in Integrated Manufacturing Technologies Research Group (IMTRG), Middle East Technical University Mechanical Engineering Department Computer Integrated Manufacturing (METUCIM) laboratory. In this model, parts and machines are considered as agents with communication capabilities. The machine/part agent is programmed to meet its objectives based on the available data on the main agent database. The messaging procedure involves a customer-server based negotiation mechanism in which the external input is given by the user (manufacturing engineer) from a locally restricted Internet web-site, thus enhancing browsing and monitoring capabilities of online data and status. There are a number of scheduling algorithms available in the literature such as Shortest Processing Time (SPT), Currency, and Pre-emption scheme [4]. Any of the scheduling procedures may be easily applied to one or several agents. The agent philosophy itself is an open architecture to implementation and selection between alternatives. User, Business, and Data Services of the "Agent" has been mostly written under Visual Basic 6.0, but it also inherits previously written Coordinate Measurement Machine (CMM) software running in host-, and client computers written in C++ for classification of parts. The host controller software for CMM has been developed by Başbüyük [2], a member of Integrated Manufacturing Technologies Research Group. For the communication and event driven messaging of agents, Microsoft Message Queue Server (MSMQ); stateless objects for database search and update has been deployed in Microsoft Transaction Server (MTS). The common database of the "Agent" has been constructed using SQL Server 7.0. Internet Information Server (IIS) has been used to grant access to the web sites ASP and HTML pages, which are designed in Visual InterDev 6.0, a product of Microsoft Visual Studio.

In summary, the developed system includes:

- 8 agent controller Win 32 EXE programs to drive the hardware components as shown in Fig. 4 accompanying 48 channels I/O card, RS 232 serial communications, MSMQ services and MTS components.
- 1 Coordinate Measuring Machine (CMM) host- and client software package (previously built, some code has been modified for agent control).
- 18 MTS components for database query, create delete, update operations, 1 stateless part agent component, and 1 messenger for MSMQ services.
- 1 relational database of SQL Server 7.0 on Internet Information Server with 12 tables and 65 stored procedures.
- 1 complete web-site with 22 ASP and 2 HTML pages to control, monitor, and manage the enterprise including detailed help and information sources.

V. METUCIM Experiment

The modeled system is a manufacturing cell placed in the CIM laboratory, which is used for the authors' research activities and the experiments of ME 445 (Computer Integrated Manufacturing) lecture. The system, which is also used for ME 445 experiments, can only be implemented from the CIM laboratory. Before coming to CIM laboratory experiment main and priority assignments for students are preparation of their part designs and NC codes related with part drawings, so that the uploading process of NC codes and part drawings to FTP site can be enhanced successfully. This system gives idea about how to integrate manufacturing process by computers through network and concurrent engineering psychology to the students. The cell has three work stations for light-duty manufacturing, an automated buffer for shared storage, an AGV and one robot having linear robot positioning device (LRPD) beneath to add one more axis to the robot. The layout of the system is given in figure 2. The operating system running on the cell controller is Windows 98 and device agents of the cell are located at this computer. The other computers are running Windows NT servers, version 4.0. The primary domain controller (PDC) is running IIS 4.0 for web hosting and MTS for hosting of part agents, plus MSMQ primary controller, for messaging needs. The backup domain controller (BDC) runs SQL Server 7.0 for storing global data of the system.

In the CIM laboratory experiment, the main aim is producing NC-Codes for a given task. In order to achieve NC-Codes, the students must accomplish firstly drawing of part. The sample drawing of part 10001 given in Figure 4 is representing the design interface of part.

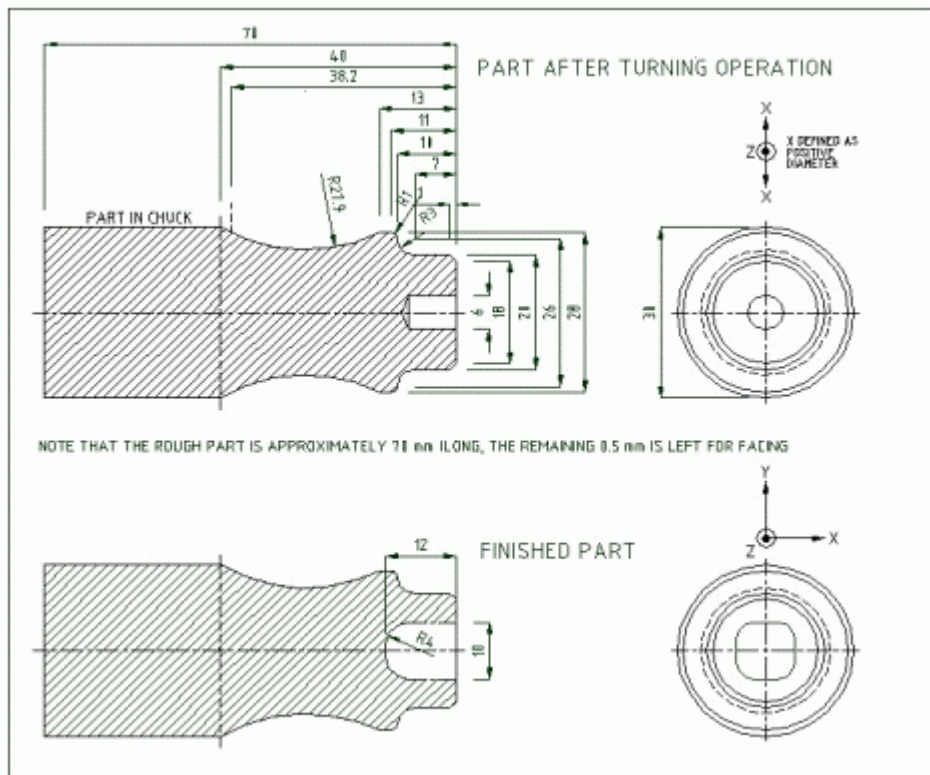
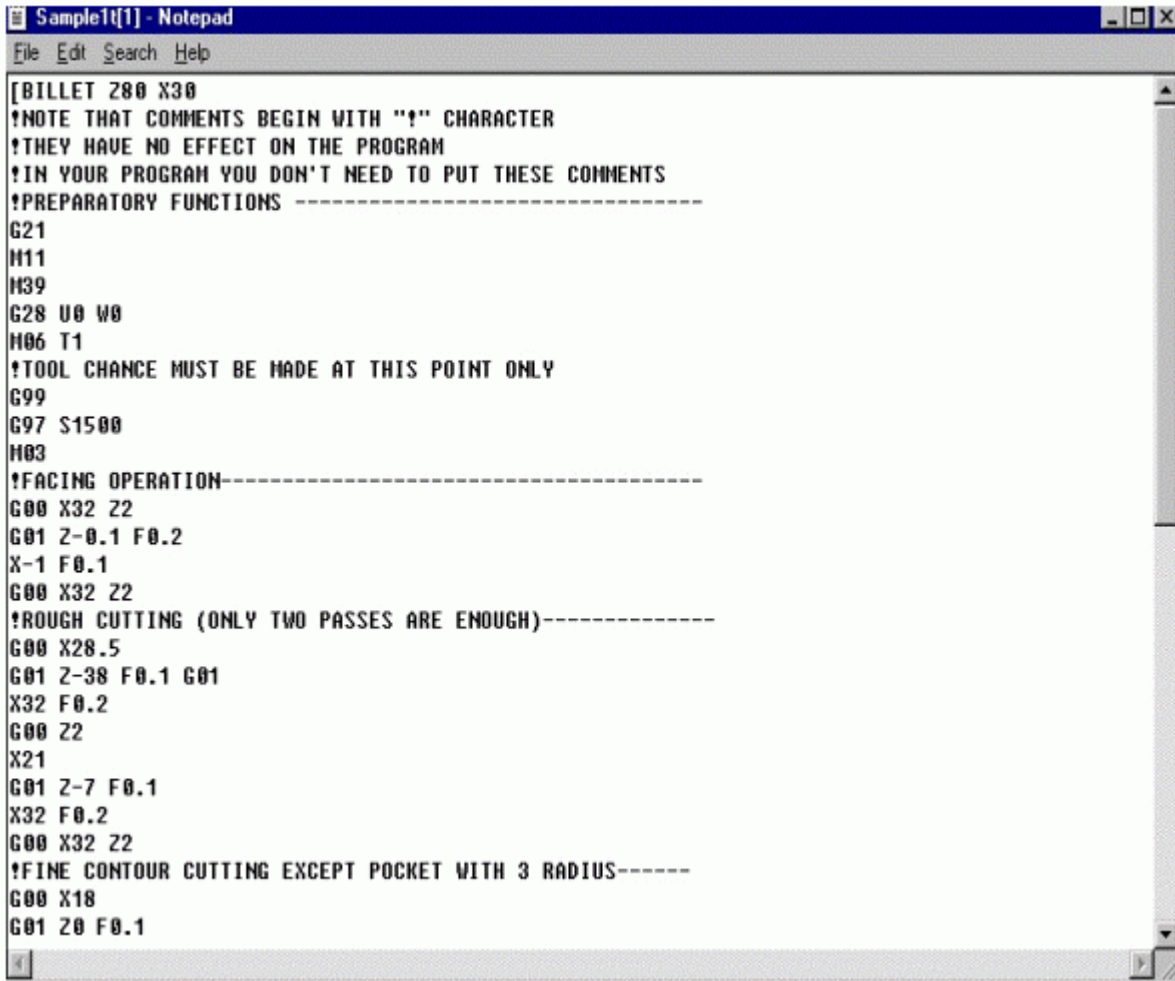


Figure 4 Drawing of part 10001

For turning operation, sample NC-Codes for part 10001 is given in Figure 5.



```
Sample1[1] - Notepad
File Edit Search Help
[BILLET 280 X30
!NOTE THAT COMMENTS BEGIN WITH "!" CHARACTER
!THEY HAVE NO EFFECT ON THE PROGRAM
!IN YOUR PROGRAM YOU DON'T NEED TO PUT THESE COMMENTS
!PREPARATORY FUNCTIONS -----
G21
M11
M39
G28 U0 W0
M06 T1
!TOOL CHANGE MUST BE MADE AT THIS POINT ONLY
G99
G97 S1500
M03
!FACING OPERATION-----
G00 X32 Z2
G01 Z-0.1 F0.2
X-1 F0.1
G00 X32 Z2
!ROUGH CUTTING (ONLY TWO PASSES ARE ENOUGH)-----
G00 X28.5
G01 Z-38 F0.1 G01
X32 F0.2
G00 Z2
X21
G01 Z-7 F0.1
X32 F0.2
G00 X32 Z2
!FINE CONTOUR CUTTING EXCEPT POCKET WITH 3 RADIUS-----
G00 X18
G01 Z0 F0.1
```

Figure 5 NC Code of part 10001 for turning operation

After conceptual design and NC-Code generation of sample part, students must upload drawing and NC-Code of part to the ftp site for necessary configuration of work-order dispatching. In figure 6, NC-Codes and part drawings embedded in the ftp site are documented.

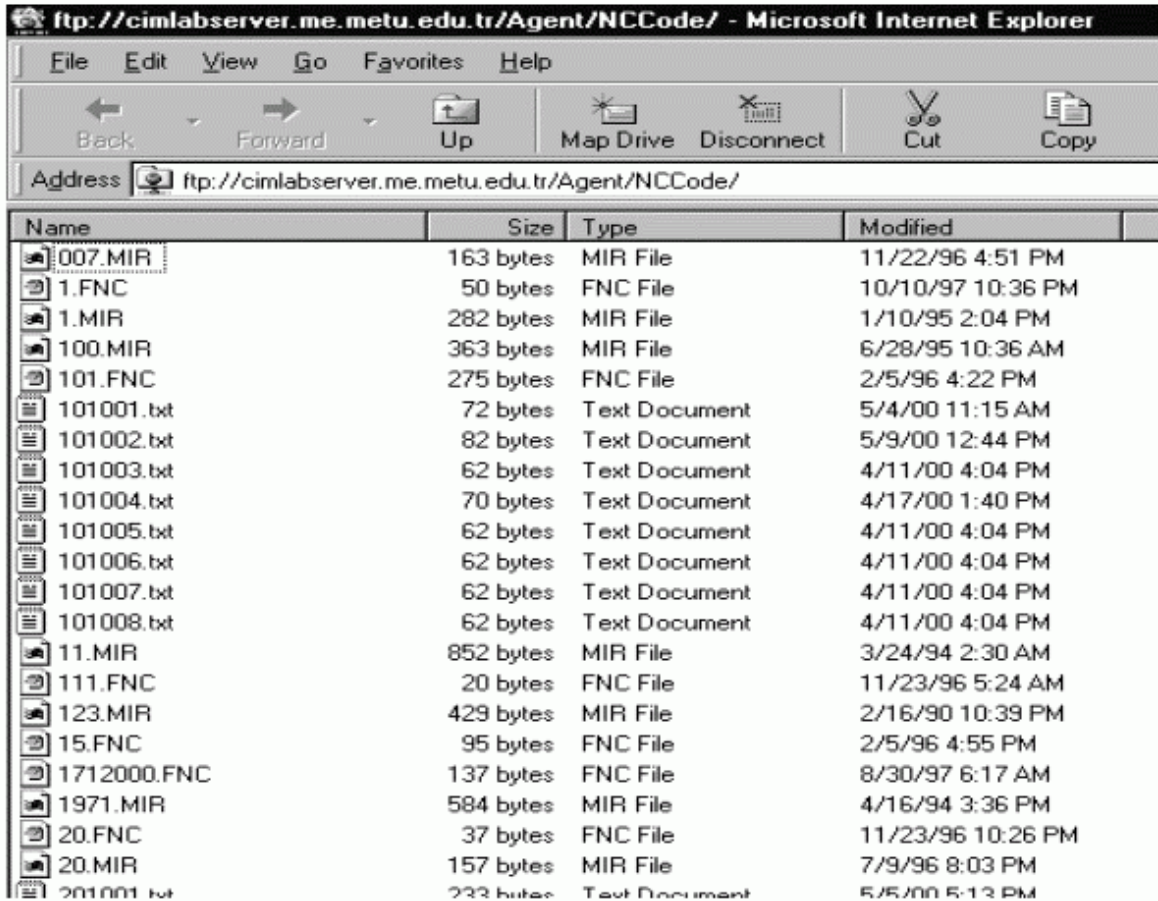


Figure 6 General view of Ftp Site

The web based presentation tier of the Agent system is implemented using ASP programming model. ASP pages enable both Client side and Server Side Scripting in VB- and Java Scripts and provide easy connection to the COM database objects. The web page of the agent can be reached from the address: <http://cimlabserver.me.metu.edu.tr/Agent>. Statistical data about the work orders, operations and tasks, lateness and tardiness values, and utilization rates can also be observed from these pages. Agent Device Drivers can also be used as integrated components to the Agent system, but also they are powerful tools in controlling the individual hardware.

The “Agent” is an actual manufacturing system to control the shop floor devices, retrieve information about parts, operations, and statistics, to form layout and relationships. People may have different roles in a society. In that manner the “Agent” system also represents a manufacturing company in which there are Administrator, Engineer, Operator, and User roles. The users are prompted to indicate a valid username and password to enter the web-site. By that, the identity of the current person is detected and stored, also unattended entries to the site are prohibited.

Figure 7 shows the complete Site Diagram of the Agent enterprise.

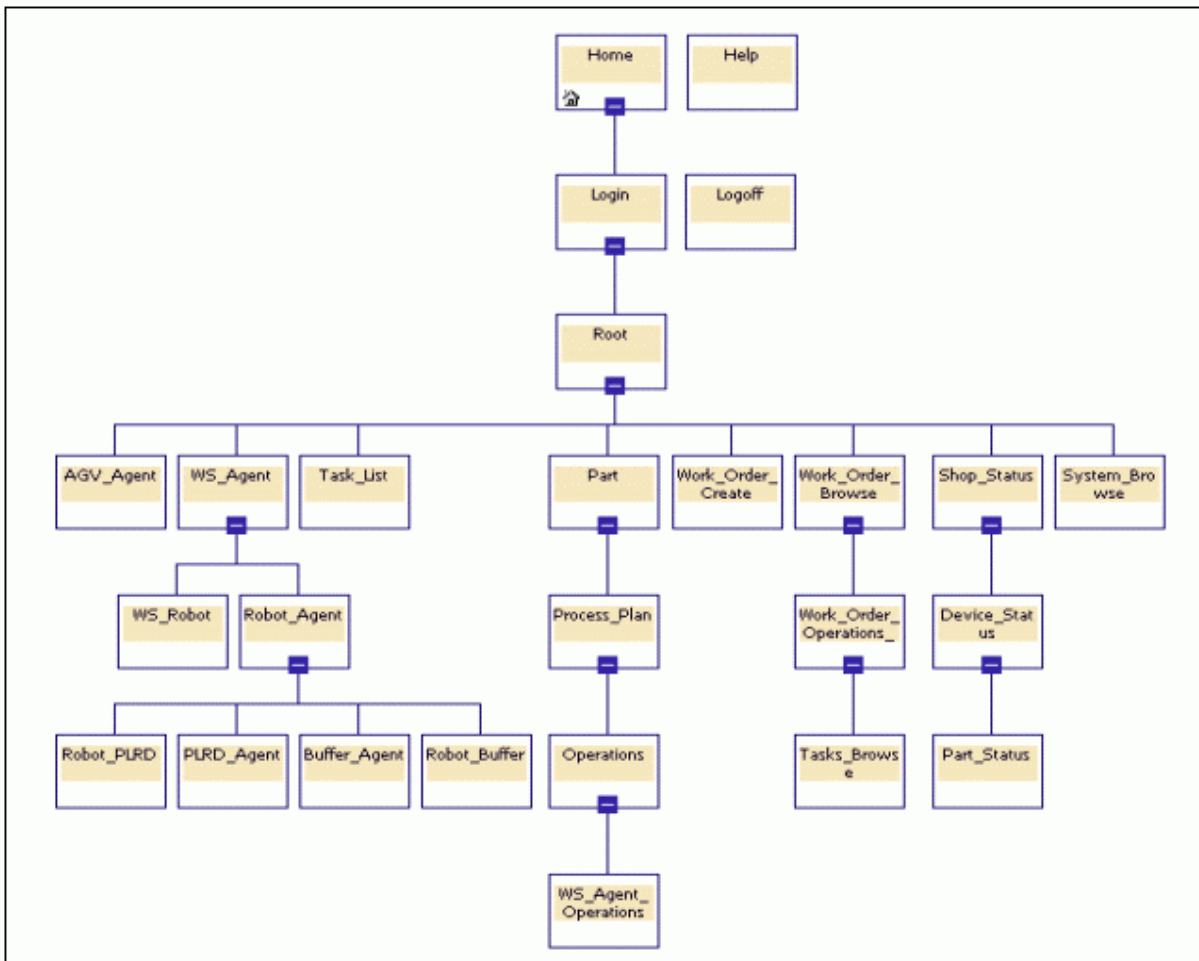


Figure 7 Site Diagram

Note that in this site, the system that is described in the hardware will be used, by giving work orders. A work order means the order for manufacturing a part, it may include the use of CNC's, CMM, robot, conveyor, PLRD and AGV as described in Part, Process_Plan, Operations and WS_Agent_Operations pages. The main entrance of the system is from [Login.asp](#) as shown in Figure 8. An ordinary user will login with Name: “user”, Password: “guest”, user can gain the

access based on "User". A user can't delete, add, modify any information contained in the agent site, nor give any work orders. However, the user can give a work order with the default parts contained and can also watch online the operational status of these work orders, according to the username and password based on "Operator".

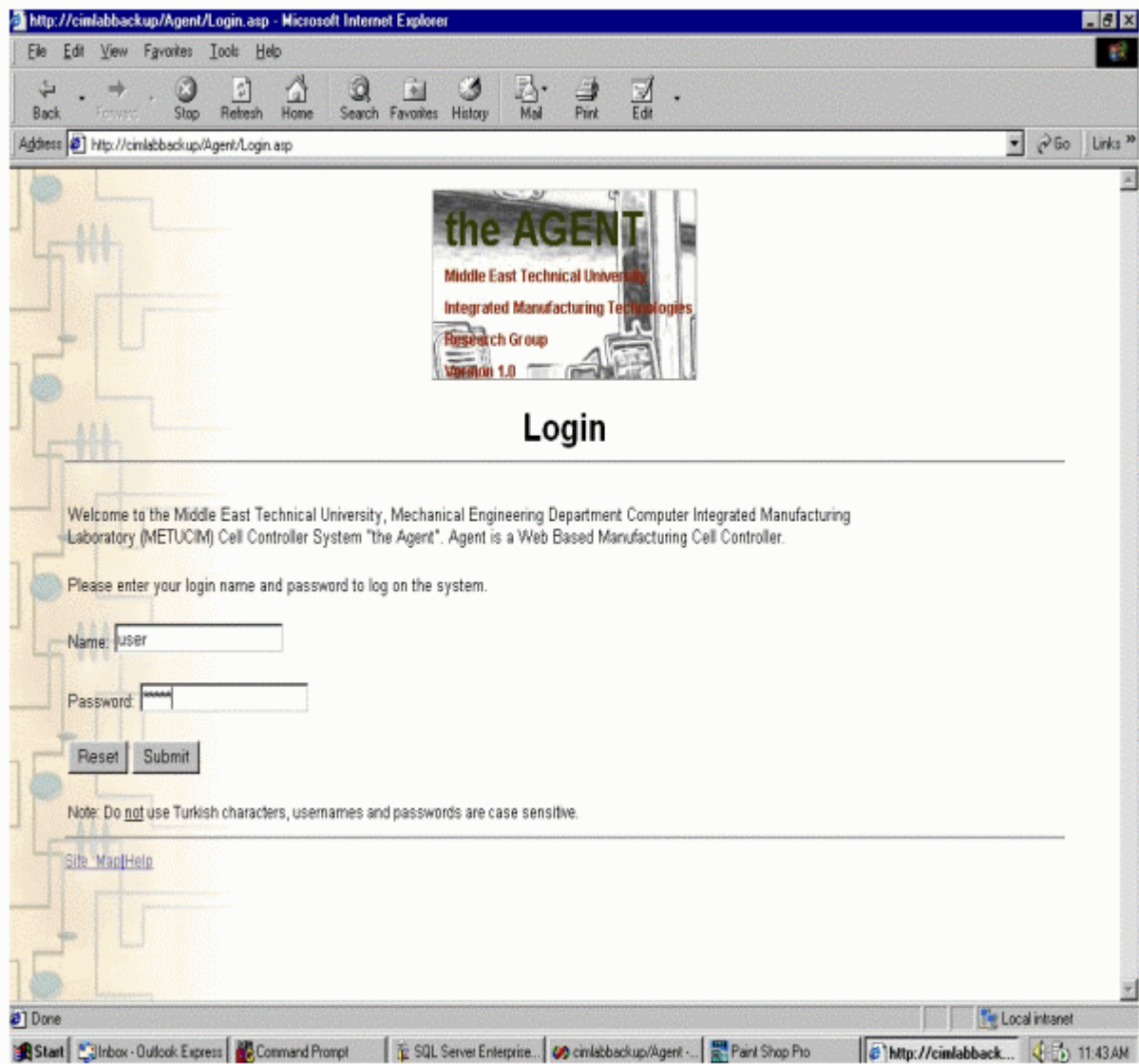


Figure 8 Login page, logon using name: user, password: guest

After logging on, root page will be seen as shown in figure 9. In this page there are links listed. They are classified as:

Static Part/Process Plan/Operational Data: Parts with drawings, their related process plans, process plan operations with NC codes, and connection between agents and their operations can be reached from this link.

Static Agent Device Data: The user can search available machines in "Agent" system. These machines are classified into 5 main groups in Automated Guided Vehicle (AGV), Workstation (WS), Robot, Pneumatic Linear Robot Drive (PLRD) and Buffer (Conveyor) pages. Note that WS_Robot, Robot_PLRD and Robot_Buffer pages are used to build connection (customer-server) relationship between these two.

Work Order Create: The user with user rights based on "Operator" may give work orders. A work-order means the order for production of a part.

Watch online system status: The user can browse the work order given, the work orders are not limited with the active ones, also previous work orders can be browsed and statistics about machining times, transport times, lateness and tardiness. The shop status gives an online watch of the workshop with automatic refreshing.

System statistics: User can find online and historical information about Part, Device and whole production system under this link.

Help: This link connects to help, login and site map screens



Figure 9 Root page, links are listed for the "user"

After logging on, students will select the desired part which will be composed of 4 sub elements: Part itself, its process plan (or plans), the operation (or operations) of the process plan, and the WS agent (or agents) in which these operations will be performed. The pages "Part.asp", "Process_Plan.asp", "Operations.asp" are used to describe these relationships respectively. Part details of 10001 are given in Figure 10.

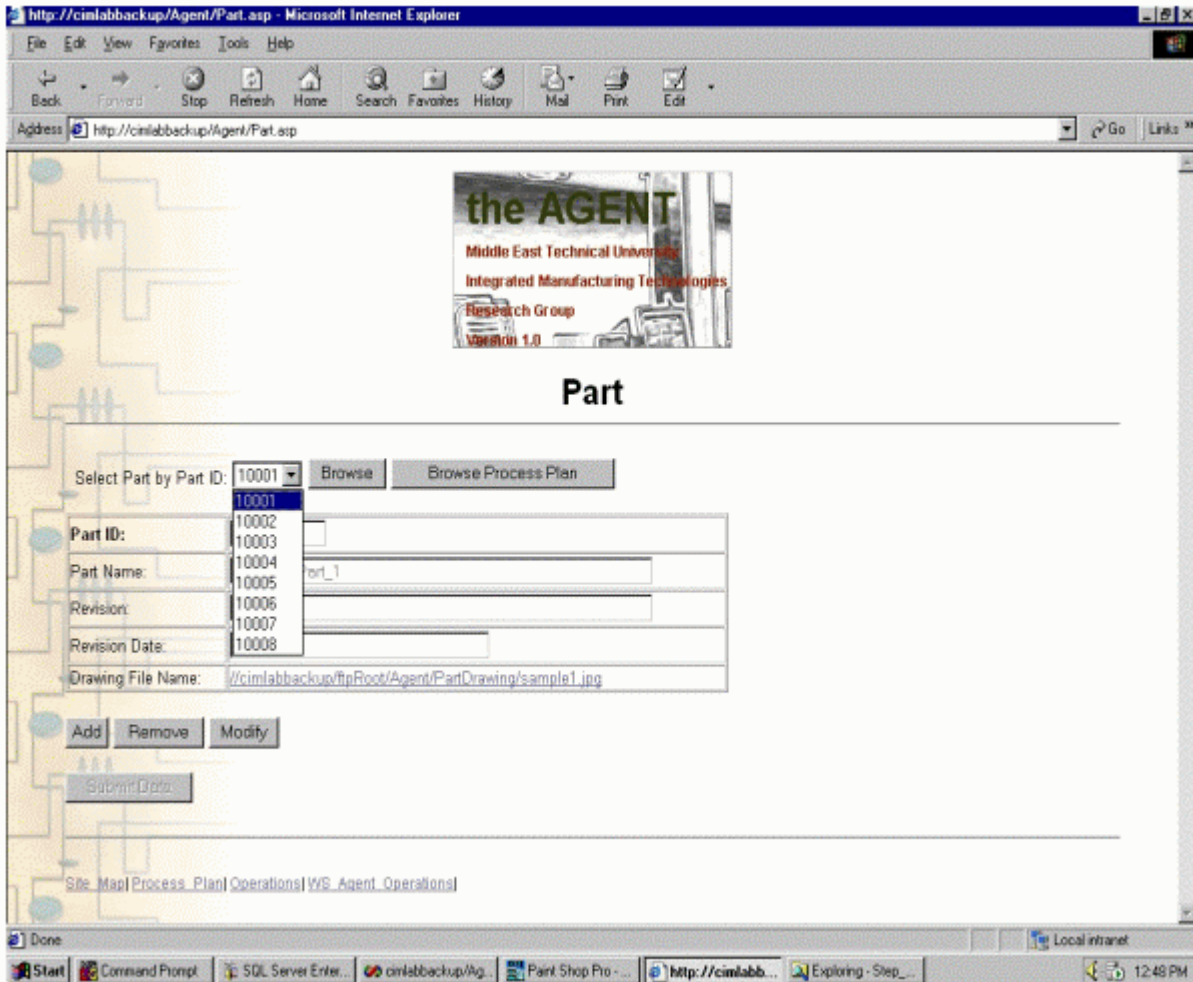


Figure 10 Part details of 10001, there are 8 built-in parts. Also the part drawing is available.

After the students click on the "Browse Process Plan" button, process plans of the part will be available for browsing. The operations of the selected part & selected process plan will come in view to the student, after further clicking on "Browse Operations button". Operations of 10001 are shown in Figure 11.

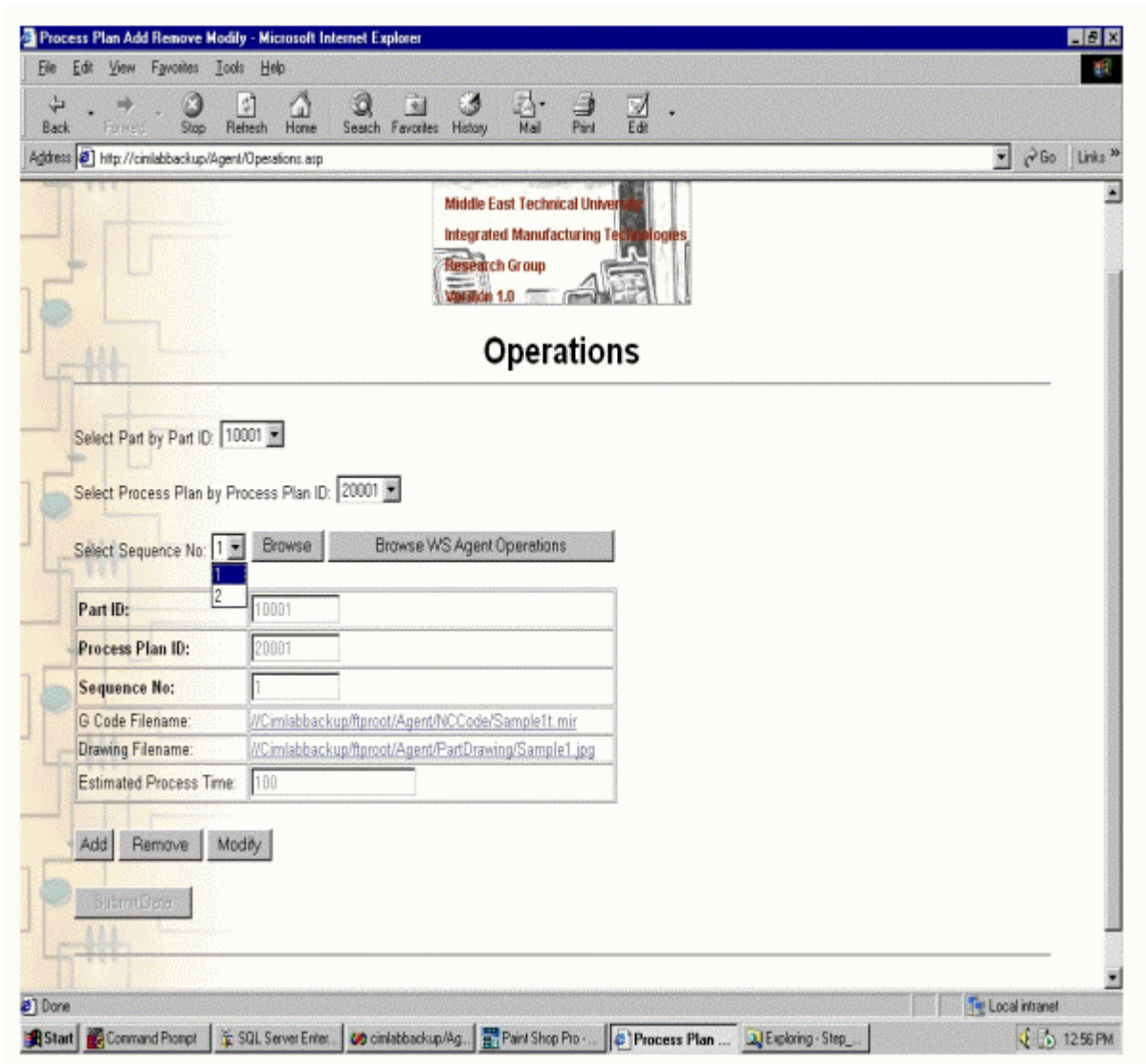


Figure 11 Operations of 10001, consists of 2 sequences, with drawing and NC-Code

After students select the related operation, they will have a chance to see, which of these operations will be performed in which WS_Agent as seen in figure 12.

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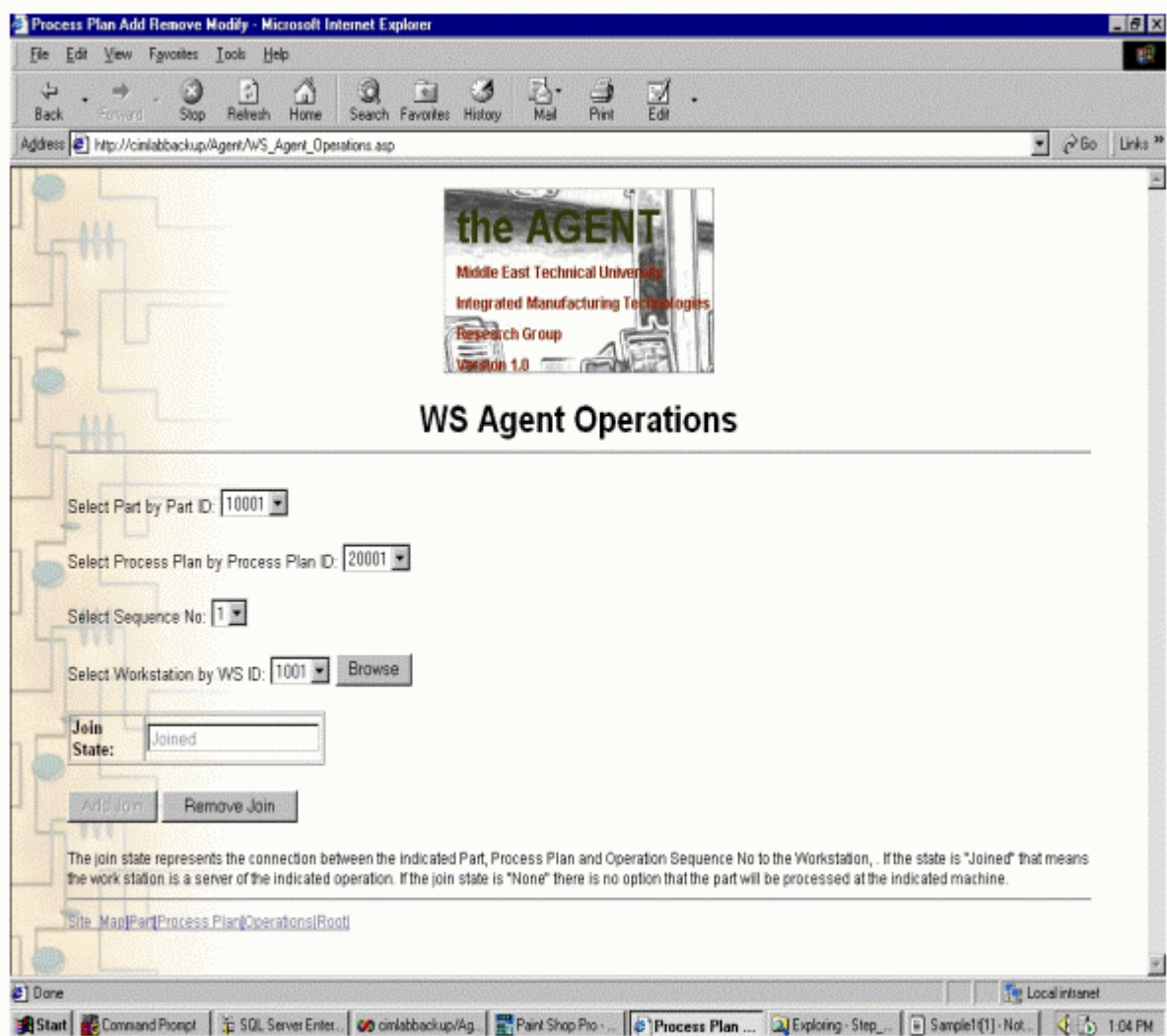


Figure 12 Relationship built between Operation and WS Agent

After browsing part, the next step will be taken as giving new work order. Note that, creating a work order means a physical input to the system. Precautions at the laboratory should be taken; otherwise any erroneous data will result in system failure. Figure 13 shows creation of new work order for achieving the desired part profile.

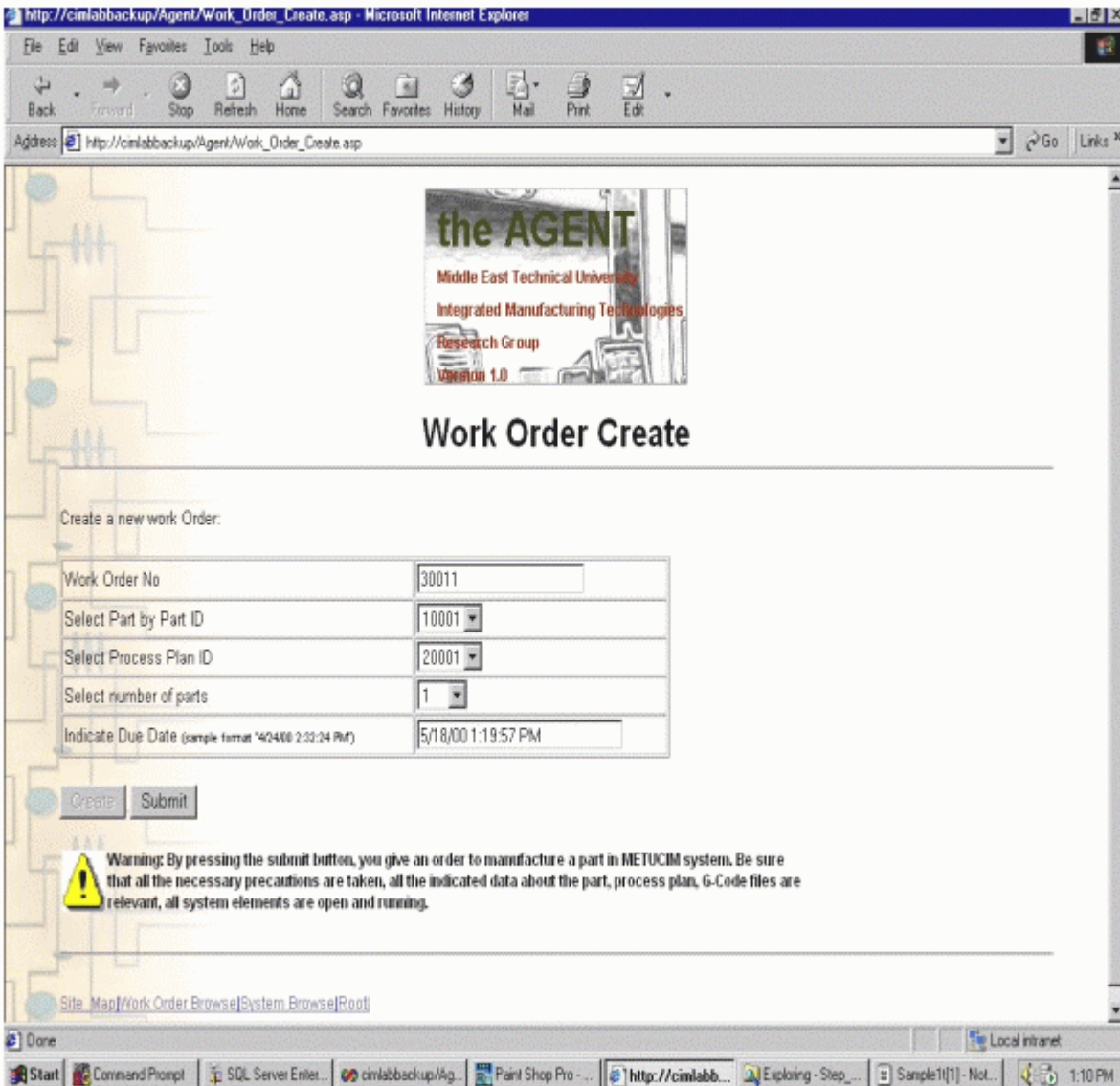


Figure 13 Creation of new work order

Users or students will also have ability to watch the online and finished status of the given work order (or work orders) as seen in figure 14. Besides that, status of the online/offline agents can be seen from figure 15.

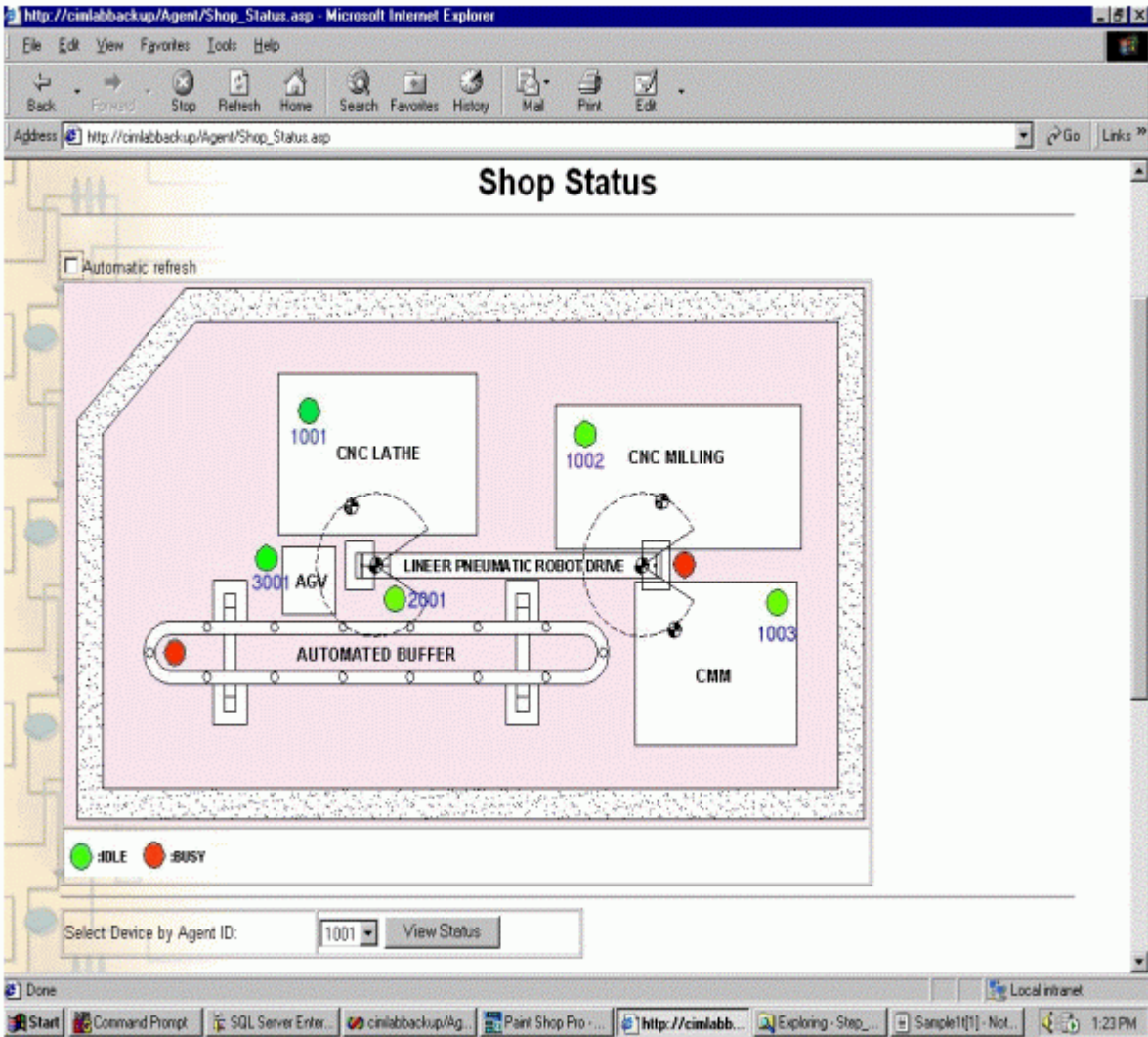


Figure 14 Current shop status

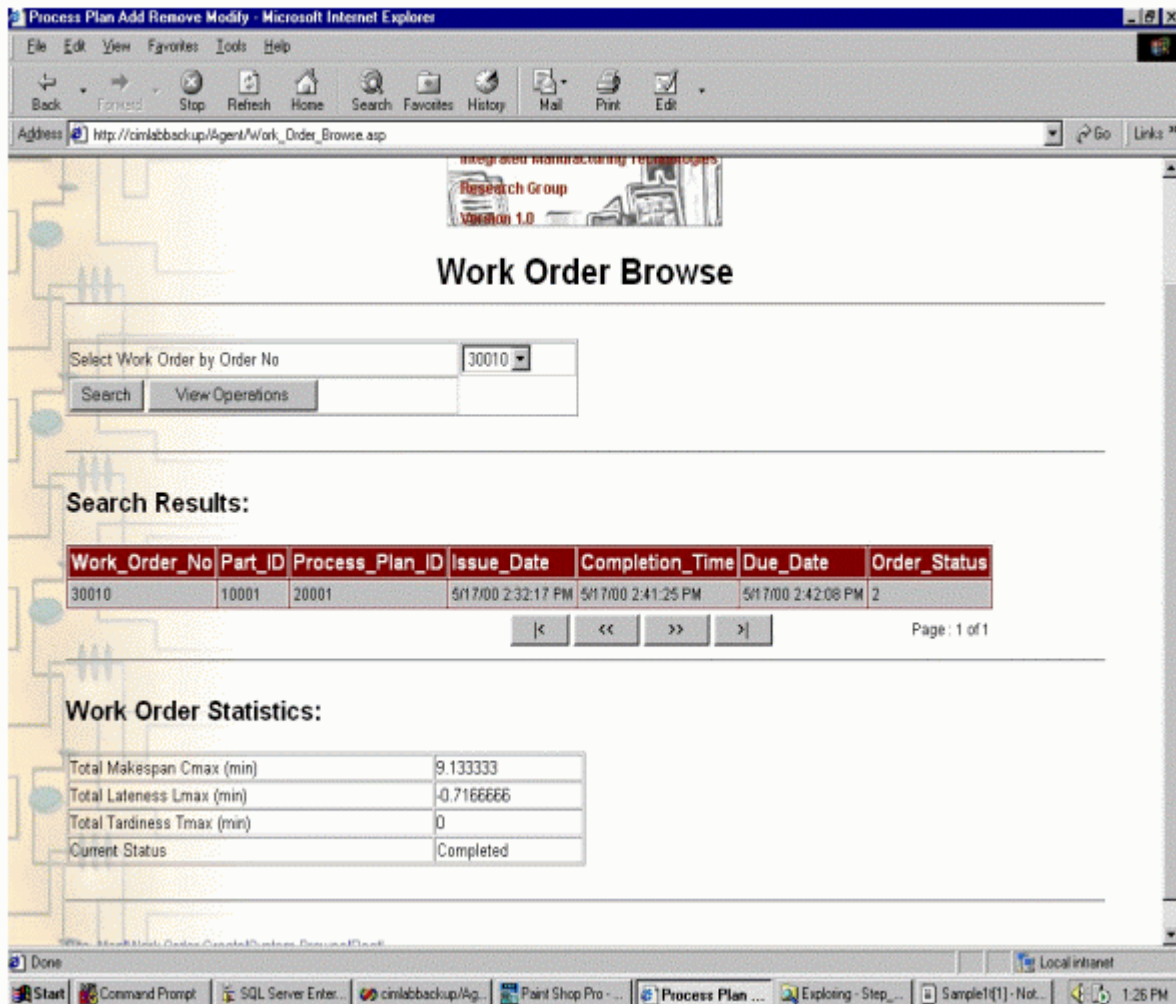


Figure 15 Work order browse

Students will be also capable of browsing the task statistics of a their completed work order from the 'Tasks Browse' screen as seen in figure 16. Note that 21 tasks were required to accomplish a single operation in a workstation agent. 26 percent of the makespan has been the productive manufacturing time, 29 percent the transport time and the remaining 45 percent has been idle.

Task Statistics:	
Total Number of Tasks	21
Number of Tasks completed	21
Number of Tasks active	0
Number of Manufacturing Tasks	2
Number of Part Agent Tasks	2
Number of Transport Tasks	17
Number of Bids Received	1
Task Makespan Cmax	14m:1s
Queue Time	15m:11s
Bidding Time	1s
Transport Time	4m:6s
Manufacturing Time	3m:37s
Idle Time	6m:18s
Manufacturing Time/Makespan (%)	26
Transport Time/Makespan (%)	29
Idle Time/Makespan (%)	45

Figure 16 Task statistics of a completed work order

VI. Conclusion

The available system on Computer Integrated Manufacturing is mainly focused on the implementation of the flexible, re-configurable manufacturing and information systems. It focuses on realizing an Agent based manufacturing cell control system with DNA technology by the use of the hardware in Middle East Technical University, Mechanical Engineering Department, Computer Integrated Manufacturing Laboratory (METUCIM), Ankara, Turkey. The result is an agent system with reduced complexity in scheduling, manufacturing execution, part routing, software generation and a well-defined communication model. The modular architecture has open doors to rapid system integration and code reuse. Browsing and visualization capabilities of the dynamic interfaces will provide user satisfaction and real-time data processing.

In this paper we have presented a concurrent approach in CIM laboratory through the use of Internet by the available software and hardware in METUCIM laboratory. By the use of the available system in METUCIM, the students are being capable of designing their own parts, writing related G codes and giving work order for manufacturing the part in a concurrent approach.

The available system in METUCIM can be interpreted as ‘putting things in place’. Its scope extends from scheduling to shop floor control with online monitoring and dispatching

capabilities from the widespread Internet environment. As a result, it is being a useful experience for the students about manufacturing processes, from design to manufacturing in an integrated environment.

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Recent Research Experience

Dates	Institution	Subject
1999-2000	METU Research Fund Project	Installation of a Pneumatic Linear Positioning Device at METUCIM
1998-2000	Turkish State Planning Organization (DPT)	Development of a shop floor control system using CORBA for Agile Manufacturing
1998-1999	TEI, Turkish Engines Industry	Distributed Numerical Control of CNC Machine Tools
1996- 1998	University of Miskolc (Hungary), METU (Turkey)	Design, Development and Implementation of an Integrated Production Management System (IPMS)
1996-1998	Bay Zoltan Institute (Hungary) and METU(Turkey)	Development of a Computer Aided Quality Control Software to Detect Machining Errors on Complex Rotational Parts

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Recent Research Experience

Dates	Institution	Subject
1999-2000	METU Research Fund Project	Installation of a Pneumatic Linear Positioning Device at METUCIM
1998-2000	Turkish State Planning Organization (DPT)	Development of a shop floor control system using CORBA for Agile Manufacturing
1998-1999	Scientific and Technical Research Council of Turkey	Feasibility Study for the Research and Development Center of Advanced Manufacturing Systems and Technology
1998-1999	TEI, Turkish Engines Industry	Distributed Numerical Control of CNC Machine Tools
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