1st year progress report on architecture design of distributed planning and control

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1st Year Progress Report on Architecture Design of Distributed Planning and Control

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EXECUTIVE SUMMARY

In today's globalized business world, the decentralization and cooperation of organizations have become a major success factor. Outsourcing, joint ventures, and cross-border collaborations have led to work environments that are geographically distributed across organizational and national boundaries. Such an environment demands quick and effective responses of business behaviors both within an enterprise and along its supply chains.

The objective of this project is to develop innovative technologies and methodologies for advanced distributed planning and control in manufacturing. The proposed framework considers issues in manufacturing from supply chain management, through shop floor planning and scheduling, down to machine real-time monitoring and control.

There are six thrust areas in this research. A collaborative environment (Task 1) called *cyber workspace* will be developed to provide a common platform for the other five tasks. The other five tasks will address supply chain planning and monitoring (Task 2), distributed process planning (Task 3), planning-scheduling integration (Task 4), remote monitoring and control (Task 5), and integrated security and privacy for collaboration (Task 6), respectively. With all components delicately interrelated to each other, the whole system forms a more advanced integration solution that can greatly enhance system flexibility, adaptability and overall performance.

This report presents the progress of the NRC-NSC collaborative research project titled "Research on Advanced Distributed Planning and Control in Manufacturing". Research of feature-based machining process sequencing, which is a part of supervisory planning of DPP (Task 3), is resumed first and many important results have been reached. High-level system analysis and preliminary design of the entire system have also been completed. Four of the six major tasks are further decomposed to enough details to show clearly how the whole system would function like and how the information and event flows would be. Some critical sub-functions, which would come out to be our major contributions and main efforts, are further described for the clarity of interpretation.

As stated on the initial proposal, NRC, universities and industries in both Canada and Taiwan will devote to different areas of the six components. It is expected that synergistic effect will be created in this project. An integrated prototype system comprising major functions will be developed as part of final deliverables of this project. Based on the system analysis and design, research and development timetable of this project is adjusted for the remaining R&D tasks.

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1 INTRODUCTION

With the growing decentralization of organizations, the boundary between "inside" and "outside" of a company is becoming blurred. Businesses now routinely exist across national boundaries. Products and services are distributed everywhere and sourced anywhere along global supply chains. In the area of manufacturing, product design and fabrication have shifted rapidly from OEMs to outsourced SMEs in the form of global networks. How to streamline activities in the decentralized manufacturing environment is a challenging issue, which led to several new concepts in the past few years, e.g., reconfigurable manufacturing [13], agile manufacturing [7], and virtual manufacturing [3]. In spite of the slight differences, the consensus of ideas or features underneath is to target the manufacturing intelligence in terms of reconfigurability, agility, controllability, and responsiveness of product development and manufacturing processes.

Modern factories, such as semiconductor wafer fabrication and mechanical parts machining plants, have high level of automation and their management are integrated and controlled by factory-wide ERP. Unfortunately, these systems are proprietary systems utilizing heterogeneous architectures, databases, platforms and development languages. The heterogeneity of these systems becomes the major barrier that hinders enterprise to do business on the global network and cooperate with each other. New integration technologies that can streamline the business processes of the whole product cycle are required at different levels – inter-enterprise and intra-enterprise.

In the area of manufacturing, the ever-changing environment is demanding for quick and accurate responses of its inside activities to reflect changes of the outside world. Traditional ways of product development (i.e. CAD-CAPP-CAM-machining) follow a sequential order, and are usually rigid, time-consuming and error-prone to withstand and win today's highly dynamic competitions. Different from traditional methods, this project partitions the activities along manufacturing processes more effectively by introducing the concepts of DPP [31] and function blocks [9]. DPP uses a two-layer structure – supervisory planning and operation planning. The former focuses on high-level machining sequence generation, while the latter focuses on machine-specific working step planning and execution. Function blocks, on the other hand, are used as the core media to integrate data, events and decision-making processes of different components together. Function block concept and its innovative application in shop floor operation management will be one of the major contributions of this project.

Recently, many research organizations and industry practitioners are devoting their efforts to bringing traditional machining tools on line. A Web-based collaborative remote monitoring and control system for manufacturing resources (i.e. machining centers, robots, AGVs) in shop floor is, therefore, integrated into this project to provide real-time support at machine level that can facilitate upstream intelligent decision-makings.

The whole picture of advanced distributed planning and control system can go from the supply chain planning, through shop floor supervisory process planning, scheduling and execution control, down to run-time machine level operational planning, remote monitoring and control. It provides a highly responsive, truly integrated framework for manufacturing industries.

All the functions described above are being developed using the Internet, Web, Java/Java3D and agent-based technology. A portal infrastructure that can handle diverse needs from supply chain planning to machine control is urgently required to keep dispersed enterprises or engineering teams connected within an e-manufacturing environment. This single point of access to all necessary resources will cut down information overload and increase productivity. Needless to say, for large Web applications, security and privacy issues are among those that are always needed to attend to.

The content of this report is organized as follows:

- Chapter 2 briefly reviews the literature related to our work. Some comparisons are made and the unsolved problems are pointed out.
- Chapter 3 describes the project from multiple perspectives. It addresses the problems, solutions, objectives, scope and enabling technologies of this project. The challenges that we may confront in this project are also highlighted by the research group.
- Chapter 4 reports our progress on system analysis and preliminary design.
- In Chapter 5, some valuable research directions in this project are identified. Adjustments have been made and a detailed timetable for future research and prototype implementation is provided in Appendix-1.
- Conclusion of this report is given in Chapter 6.

2 LITERATURE REVIEW

In this section, we will provide a brief review of the literature related to our research work in this project including computer-aided process planning (CAPP) and Internet and agent applications in manufacturing.

2.1 Computer Aided Process Planning

Process planning is known as an integral task between design and manufacturing. There are numerous factors that affect process planning. Part geometry, tolerance, surface finish, material, quantity and the available resources (machines, fixtures, and cutting tools, etc.) all contribute to decision-makings in process planning. From product data in design to NC data in actual machining, a number of steps must be followed, including setup planning, process sequencing, tool selection, tool path planning, operation optimization, NC data generation, and fixture design. These activities are knowledge intensive, complex and dynamic in nature [14].

Since 1965 when B. W. Nieble reported the first CAPP system [16], CAPP has continuously been among the hottest research areas in manufacturing. Previous research studies on process planning include object-oriented approaches [39], genetic algorithm-based approaches [38], neural network-based approaches [15], Petri net-based approaches [11], feature recognition or feature-driven approaches [29], as well as knowledge-based approaches [25]. These approaches and their combinations have been applied to specific problem domains in process planning, such as tool selection [6], tool path planning [1], machining parameters selection [8], process sequencing [37], and setup planning [35].

Recently, research focus of process planning is moving towards solving problems in distributed manufacturing environments. Tu et al. introduced a method called IPP (incremental process planning) for one-of-a-kind production (OKP) [26] in such environments. The IPP is used to extend or modify a primitive plan (a skeletal process plan) incrementally, according to new features that are identified from a product design until no more new features can be found. A complete process plan generated by the IPP may include alternative processes.

In addition to centralized AI approaches (e.g. genetic algorithms, neural networks, fuzzy logic, expert systems, etc.), agent technology as a solution for distributed artificial intelligence has attracted wide attentions. CoCAPP (Cooperative CAPP) attempts to distribute complex process planning activities to multiple specialized problem solvers (agents) and to coordinate these agents to solve complex problems [40]. Each agent in the system deals with a relatively independent domain of process planning. Zhang et al. proposed an AAPP (Agent-based Adaptive Process Planning) system on top of an object-oriented manufacturing resources modeling framework [39]. Five agents are defined in the AAPP to carry out part information classification, manufacturing resources mapping, process planning, human planning, and machining parameter retrieval. A contract net-based scheme is utilized as the coordination protocol between agents.

2.2 Internet and Agent Applications in Manufacturing

Multi-agent modeling has emerged as a promising technology for dealing with cooperation and decision-making processes in distributed information systems. Early research work on agent-based intelligent manufacturing scheduling and factory control was reported more than 10 years ago [12][17][18]. A number of researchers have attempted to apply agent technology to manufacturing integration, supply chain management, manufacturing planning, scheduling and execution control, materials handling, and holonic manufacturing systems [19].

Agent based manufacturing has become a new paradigm for next generation manufacturing systems, together with other manufacturing paradigms such as Holonic Manufacturing Systems [27], Agile Manufacturing [7], and Reconfigurable Manufacturing [13]. Except for the slight differences existing in these paradigms, the consensus ideas or features underneath are distributed control, distributed decision-making, self-organization, and cooperation. We have conducted an extensive literature review and published the review results previously [19][21].

During the past decade, the "explosive" evolving of the Internet and the Web has made it the most suitable enabler to implement geographically distributed applications. A number of methods and frameworks have been proposed for building Web-based systems for collaborative design and manufacturing. Examples of such systems include *CyberCut* [24] for Web-based rapid machining, *WebCAD* [10] for on-line manufacturability checking of feature–based design, *WebCADET* [2] for distributed design support, *WEB-DPR* [36] for supporting asynchronous collaboration among distributed groups of engineers to carry out complex product realization activities over the Internet and *NEMI* [5] for a plug and play factory shop floor line control. *MetaMorph II* [23] introduced a hybrid agent-based mediator-centric architecture to integrate partners, suppliers, and customers in a dynamic manufacturing environment.

A few commercial Web based visualization tools have been available recently, such as *VisualPlant* [45] and *Visual Manufacturing* [41][43]. However, all these tools are usually used for shop floor data/information collection, analysis, reporting, and integration with other business systems. In the area of event monitoring, the latest *Cimplicity* from GE Fanuc Automation (USA) allows users to view their factory's operational processes through an XML-based *WebView* screen, including all alarms on every *Cimplicity* system [34]. Similar approaches on the application of XML to the management and monitoring of shop floor information can be found in [5][28]. Upon the machine tools execution level, the number of CNC machines capable of linking to the Internet is less than 10% of the installed base according to some estimates [34]. In order to seek the opportunity in linking CNC machines with the Internet, MDSI (Ann Arbor, MI, USA) uses *OpenCNC* [44], a Windows-based software-only machine tool controller with real-time database, to automatically collect motion and PLC data and publish machining and process data on a network. The e-Manufacturing Networks Inc. (renamed as MEMEX Electronics, recently) (Canada) introduces its *ION Universal Interface* and *CORTEX Gateway* [42] to help the old systems go online. Some commercial CNC controller vendors, such as Hitachi Seiki and Mazak (Japanese based companies), have also started to provide solutions from the late 1990s for putting machining centers on public networks other than the serial port communication over DNC. We have done a comprehensive survey of similar projects/devices from 21 different vendors [4].

In terms of technologies used in the existing systems, HTML, Java applets, ActiveX, and VRML (virtual reality modeling language) are widely adopted for developing the client-side user interfaces. At the server side, technologies including JSP, Java Servlets, JDBC and XML are quickly obtaining attention for new system developments.

3 PROJECT DESCRIPTION

3.1 Problem Identification

From the literature reviewed in the previous chapter, several problems are identified by the research group. They are targeted as the main objectives of this project.

3.1.1 Distributed Process Planning and Information Integration

Process planning is generally considered as an integral step between product design and manufacturing. It is a very complex task because there are a great number of steps involved in process planning, such as geometry & tolerance analysis, process sequencing, cutting tool selection, tool path planning, operation optimization, NC code generation, as well as fixture design and set-up planning. As a result, the factors that affect the decision making process and the result of process planning are considered myriad.

Most CAPP systems available today are centralized in architecture, vertical in sequence, and off-line in data processing. Due to the fact that most of the existing CAPP developments attempt to address very detailed machining information (i.e. machines, tools, fixtures) all at once from the beginning, no matter what kind of technologies or approaches employed, it is impossible for them to create general and stable process plans that can apply to new workpieces without knowing the actual real-time status of machining processes. Existing efforts towards generative process planning remains very insufficient under the constantly changing manufacturing environment. Tedious iterations acted upon the original process plan will not only cause serious data inconsistency in an ERP system but also may make the process plan lose its function (become useless) as a guidance for the following machining steps. From the Concurrent Engineering point of view, an all-at-once CAPP planning mechanism is the major part against the concurrency ethic.

The centralized control of process planning and machining operation must be split up to make the manufacturing system perform more effectively. With this question in mind, Distributed Process Planning (DPP) is a distinctive solution we proposed to address process planning problems in the advanced manufacturing planning and control architecture. Two layers of planning called supervisory planning (SP) and operation planning (OP) are identified to separate the generic process data from the machine specific ones. The former focuses on product data analysis, feature-based reasoning, and machining sequence generating, while the latter considers the detailed working steps of the machining operations within each process plan. The supervisory planning is generally performed only once, in advance, at shop floor level, followed by the operation planning accomplished at real-time at machine level by intelligent open architecture CNC controllers. In this way, the stability of SP and the flexibility of OP will make process plans react quickly and effectively to the constantly changing environment of supply chains and shop floors.

The mechanisms of DPP cause a change in shop floor management integration. The information flows among SP, OP, Scheduling, execution control, and actual machining processes are thus changed to new patterns. Execution control is selected as the functional integration point for this project. The events coming down from supply chains or up from individual machines are sent here and handled for decision-making. The scheduling information is also merged for the direction of dispatching. Technologies of information integration and event handling under this new situation are another research topic of this project. Innovative application of function block, being a media and solution for information integration and control in process monitoring and CNC control fields, will be one of our major contributions.

In terms of shop floor dynamic scheduling, a stand-alone GA-optimized multi-agent approach will be adopted and integrated in the execution control to accomplish the tasks of job allocation in shop floors. Scheduling will provide connections of general machining sequence plans (generated by supervisory planning) with machines, give execution control module the direction of downloading, and perform rescheduling when requested. In addition, a central scheduling algorithm is invoked at a regular basis as a supplementary means for global optimization. The research on scheduling will be based on our experienced accomplishments in the area of agent-based scheduling of intelligent shop floors [20].

3.1.2 Collaborative Monitoring and Control

As collaborative applications emerging, there is increasing pressure for full capabilities including audio, video, and 3D graphics to be seamlessly integrated into an intuitive working environment. Users are now demanding such an environment that is easy to follow, operate, and maintain. However, most multimedia applications require a large amount of data being transmitted through the network before the data can be shared. The limited Internet bandwidth is a bottleneck for such applications. It becomes unpractical especially when real-time constraints are encountered – shop floor being plugged into the environment. Shop floor monitoring and control needs to be deterministic. Transmission time for a signal to get from one place to another must be sufficiently short because machines need to be able to respond to a remote user's request in a timely fashion.

From the review of Web applications in machining visualization, open architecture machine controllers and virtual manufacturing, we have noticed that the available systems are either for off-line simulation or for monitoring only. Most systems require a specific application (CAD or visualization tools) to be installed instead of a standard Web browser, which eliminates a system's portability. To be more competitive, users are now demanding an integrated solution based on open architectures provided by the Web technology.

Our ongoing research on shop floor remote monitoring and control called *Wise-ShopFloor* will be integrated into this project to provide bottom-up supports/feedbacks (machining status and events) for upstream modules. Web and Java 3D technologies are the main enabling technologies used in this system. A snap shot of *Wise-ShopFloor* system is shown in Figure 1. A number of physical devices (e.g. a machine, a robot, or a production line, etc.) can be represented by a set of Java 3D models with behavior control nodes embedded. The behavior of each model is driven by the real-time sensor signals of its physical counterpart. Sensor signals are generally much smaller in data size if compared with camera images. They are collected by a data collecting servlet and distributed to their subscribers by retrieving a registrar. Intelligent algorithms are being developed to authorize and synchronize user control to manipulate a physical device from a Web browser. An embedded navigation function will enable users to virtually walk through the *Wise-ShopFloor* for intuitive monitoring and inspection. Research on sensor-driven virtual reality and its application in real-time shop floor monitoring is a challenge issue in this project.

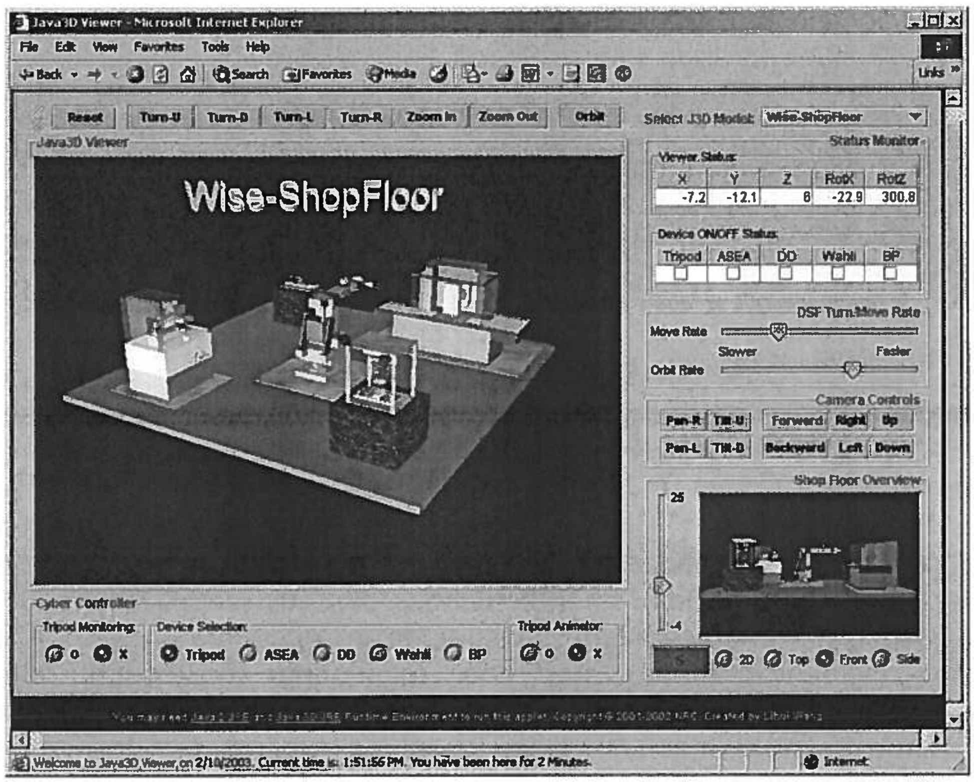

Figure 1: *Wise-ShopFloor* interface

3.1.3 Inter-Enterprise Integration

The decentralization and cooperation of organizations has become a major success factor for enterprises to win today's global market. EDI (Electronic Data Interchange) is the earlier industrial effort toward the integration of business processes and information among multiple enterprises. However, with the "explosive" development of information and communication technologies, the Internet has become the ideal and matter-of-fact technology serving this purpose.

Modern factories have high level of automation and their management are integrated and controlled by factory-wide MES or ERP. Unfortunately, all these systems are proprietary systems utilizing heterogeneous architectures, databases, platforms and development languages. Moreover, most of existing enterprise management systems were implemented several years ago and they are not developed based on the Brower/Server architecture. So the heterogeneity of these systems becomes the major barrier that hinders enterprise to do business on the global network and cooperate with each other. New technologies that can integrate heterogeneous legacy systems should be developed in this project.

Again, agent technology is adopted to facilitate the enterprise cooperation (negotiation) process; while some newly emerged Web standards, such as XML, SOAP and Web services, need to be applied for the supply chain and enterprise management modules to form a high-level loosely-coupled and interoperable infrastructure over the Web.

3.1.4 Integral Portal

The whole picture of advanced distributed planning and control system can go from the supply chain planning, through shop floor supervisory process planning, scheduling and execution control, down to real-time machine level operation planning, monitoring and control, which provides a highly responsive, truly integrated framework to manufacturing industries.

All the subsystems described above will be developed using the Internet, Web, Java/ Java3D and agent-based technology. Hence there is a need to interact with users through an integrated portal, which we call *Cyber Workspace*. This portal can keep dispersed enterprises or engineering teams being connected within an e-manufacturing environment. Just as the name *Cyber Workspace* implied, all kinds of users will work together as if they are under a single roof. Although all the system function appears to be central from a user's perspective, they are not central but distributed. This single point of access to all necessary resources will cut down on information overload and increase productivity.

3.1.5 Security Concerns

A major concern of implementing Web-based collaborative manufacturing systems is the assurance that proprietary information about the intellectual property owned by the organization or information about the company's operations is available only to its authorized roles. Web-based manufacturing involves sharing intellectual property in the form of detailed engineering and manufacturing information as well as competitive information in the form of order and costing details. For general acceptance of this approach, the secrecy of the proprietary or competitive information must be maintained.

Security issues must be considered on two levels: external user authorization and internal user authorization, because all the users come in from the same portal. On structural perspective, authentication and authorization is done on a two level basis: at the portal or at the individual function component. A preliminary study dealing with the security and privacy requirements for collaborative manufacturing has paved the way for this project [20].

3.2 Objectives

The primary objective of this project is to develop a well-shaped, well-secured collaborative manufacturing system that covers the life cycle of product manufacturing. Advanced technologies for distributed planning and control in manufacturing and innovative utilization of function blocks as major data and event integration media will be the focuses of this research. Based on the concept of *Cyber Workspace* [32], a Web and Java based collaborative environment is being developed by the project participants, on top of which emphasis will be given to research on manufacturing planning/scheduling, distributed process planning, remote monitoring and control, as well as security support for collaboration. Enabling technologies needed for collaborative manufacturing planning, scheduling, monitoring and control will also be developed, from supply chain and enterprise levels to shop floor and machine levels. This project also includes business modules that can bestow intelligent, adaptive capability on MES to significantly improve the controllability and predictability of factory operation, and can streamline multi-level planning and scheduling activities, seamlessly and effectively based on an advanced integration framework. The so-developed system will allow distributed industrial practitioners and dispersed engineering team members to work together toward the goal of achieving customers' satisfaction, maintaining core competency, co-winning on global market, and maximizing profitability.

The whole system will run together in a common portal *Cyber Workspace*. As a result, this integral feature provides an industry practitioner with a number of novel approaches, in particular, distributed process planning, scheduling, monitoring and control over the Web, compared to traditional manufacturing management systems. The Internet and the integrated portal mechanism of this system make it available to all browser users while the security and privacy of business process and related data can be protected with authentications, authorizations and security policies properly embedded.

3.3 Project Scope

The scope of this project includes six tasks as shown in Figure 2, each of which is briefly outlined below:

- Enabling technologies for collaborative planning and monitoring at both the enterprise and supply chain levels (Task 2). Legacy manufacturing execution systems (MES) or enterprise resource planning systems (ERP) of modern factories must be integrated in the framework for:
  - Protecting precious investment;
  - Maintaining the stability of existing information and business processes;
  - Reducing time and money for new developments…

- Technologies for distributed process planning, using a two-layer structure – supervisory planning and operation planning (Task 3). Different from centralized planning methods, the job of low-level operation planning will be accomplished by appropriate machine controllers at runtime, based on machine dynamics, to achieve better product quality and improved productivity.

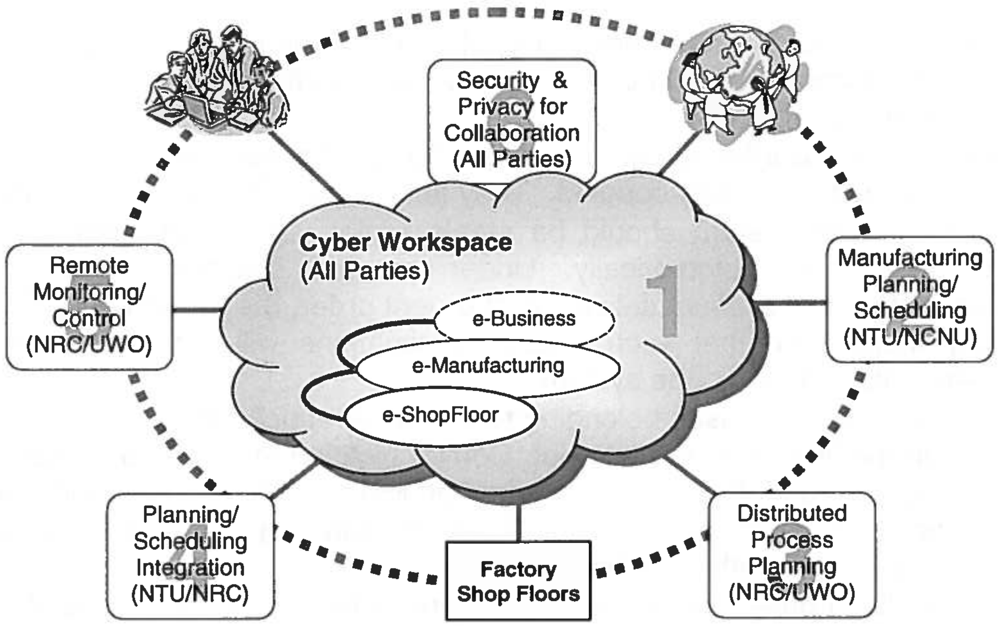

Figure 2: Scope and responsibility

- Integration of scheduling, process planning (both SP and OP), and machining processes (Task 4). Complex interactions between process planning, scheduling, (process) monitoring, and execution control will be modeled and harnessed. Function blocks are considered as a new means to achieve this goal.

- Enabling technologies of Web-based (production line/equipment) monitoring and device control for manufacturing shop floors (Task 5). Sensor-driven 3D graphics, instead of camera, will be used to achieve the required network performance. Sensor data collection and distribution, machining event generation and machine operation control will provide bottom-up supports for upstream decision-makings.

- A well-shaped, well-secured *Cyber Workspace* (Task 1). This is the single entry to system functions of Task 2-5, and will be the common platform for users to fulfill their duties.

- Security and privacy issues associated with the proposed manufacturing framework (Task 6). Digital rights management for information access and sharing, confidentiality protection, and trust mechanisms for assessing collaboration performance will be the research potentials.

3.4 System Requirements

3.4.1 Functional Requirements

The functional requirements have already been described in Sections 3.1 and 3.2.

3.4.2 Performance Requirements

- Scalability. The system should be able to facilitate the integration of new applications and new technologies easily without affecting the other components of the system.
- Loosely coupled integration. The dependency of subsystems developed in this project should be loosely coupled. They act upon each other through messages.
- Reliability. The system should be stable under various interruptions and can adapt to changes automatically. Under emergent situations, such as machine failure, latency of product delivery and urgent order, the system should react in a timely manner so that such emergent situations will not reach the point of causing fatal failures in the system.
- Security. The enterprises belonging to the same supply chain interacts through a common medium, e.g. the Internet. Communication infrastructure should protect them against unauthorized accessing of information or operations. Important business and control logics should be carefully deployed to a well-protected application server within a firewall.
- Privacy. Enterprise can protect its manufacturing information and logics of business processes from others. External business functionalities and information should be separated from their internal counterparts.
- Efficient communication. Communication between and inside enterprises may induce high network traffic. Efficiency of communication of Web-based applications is always a big concern for real-time systems, such as manufacturing planning and control systems. In this project, particularly, Task 4 and Task 5 should be real-time oriented to adapt to the dynamic shop floor environment.
- Reusable. All tasks will be researched and developed simultaneously. From the software point of view, each function is designed as an individual module or a stand-alone package to maximize the modularity and reusability as much as possible.
- User friendliness. The user interfaces and operations should be user friendly. Microsoft Windows style interface is used as the default graphical user interface (GUI). Standard Web browser is used as the accessing gateway to system functions and information.
- Portable. The entry of the entire system is Web-based. What end users need are standard Web browsers and network connections. No specific application is required to be installed at client side.

3.4.3 Information Requirements

- Information (and/or knowledge) is logically and physically distributed in many databases (Web servers).
- Information must be exchanged and shared among enterprises.
- Information must be exchanged and shared among different applications inside an enterprise.
- Information and/or knowledge must be stored and partitioned securely with appropriate mechanisms to assure authorized accessing.

3.5 Enabling Technologies

3.5.1 Machining Features

Machining features [33] are used as information carriers from product design to process planning and NC machining. Machining features are those shapes such as step, pocket, slot, ring, and hole that can be easily achieved by the available resources and machining technologies. Different from design features used in CAD system, each machining feature holds a set of loosely coupled information about how to fabricate it, e.g. cutting tool suggestion, machining sequence, cutting strategy, and tool path generation logic. By utilizing such kinds of information carried by machining features, the time and efforts for the process planning tasks can be significantly reduced. Twelve typical machining features are identified and considered in test parts for DPP prototype demonstration (Figure 3).

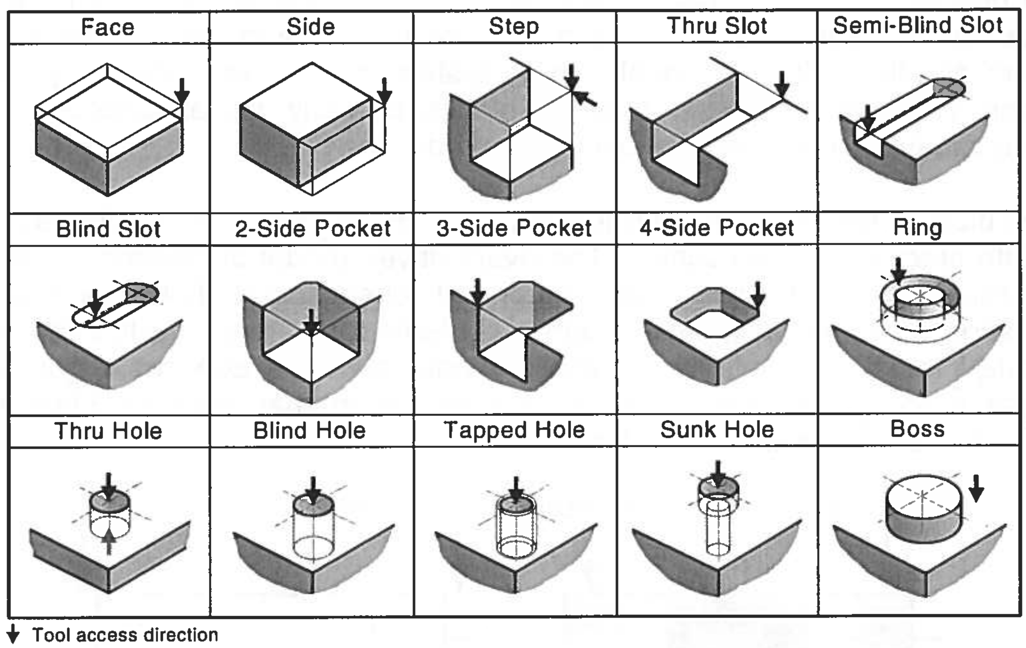

Figure 3: Typical machining features

3.5.2 Agents

Agent technology has been applied in attempts in manufacturing field for collaborative design, supply chain management, manufacturing planning, scheduling and control in the past decade. We have conducted an extensive literature review and published the review results previously [19][21].

Multiple agent-based coordination approaches will be used in partners searching and selection process during supply chain/virtual enterprise formation and the resource allocation process in shop floor scheduling module.

3.5.3 Function Block

Function block is chosen for machining process encapsulation and CNC control execution. In this section, we provide basic introduction of IEC 61499 standard [9] and our application of function block in this project. Detailed descriptions can be found in Section 4.6.

There is currently an explosion in the use of object-oriented technologies and software components in business systems. Control and system engineers, facing with more and more complex and distributed systems, are also starting to adopt these techniques and trying to utilize the merits of object-oriented methodologies in control field. The IEC 61499 defines concepts and models so that software components in the form of function blocks can be applied to distributed industrial process, measurement and control systems.

The introducing of object-oriented concept brings a number of benefits to system implementations, such as abstraction, encapsulation, and polymorphism. System engineers are thus able to model a new system quickly and effectively, simply by combining the reusable basic function blocks properly as experienced hardware engineers create electrical circuits using standard chips.

Function block is based on an explicit event driven model and provides for data flow and finite state automata based control. The event driven model of function blocks is used for integration of SP, OP, execution control and scheduling at shop floor and machine levels. Being an atomic distributable and executable software unit, a function block can encapsulate much more information (data, events, states, sequences, algorithms, etc.) for a given machining feature. Figure 4 illustrates the internal structure of both the basic (left) and the composite (right) function blocks.

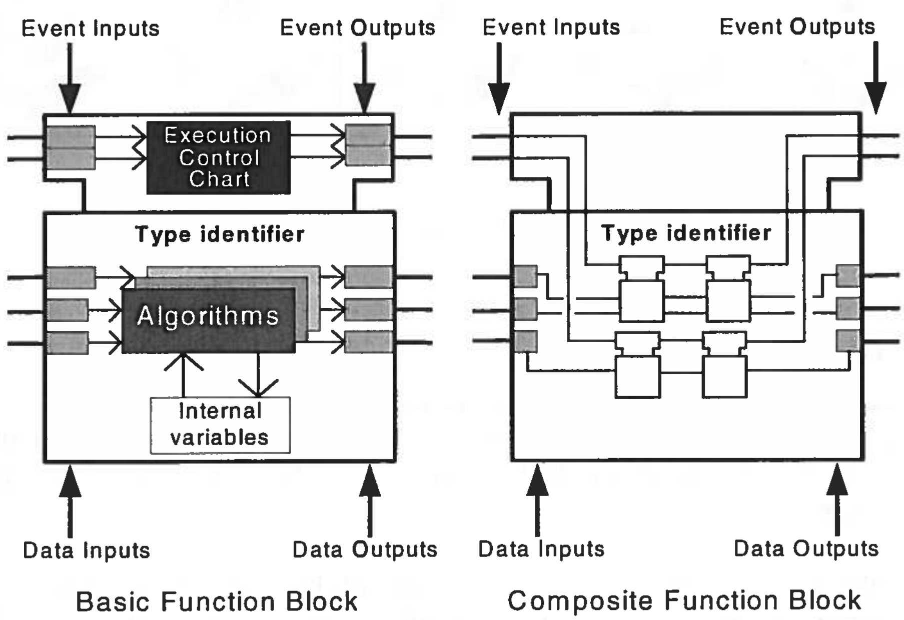

Figure 4: Function block structure

Basic function blocks encapsulate data, events and algorithms, while composite function blocks only combine basic function blocks or other composite function blocks. A combination of both basic and composite function blocks is used to define the needed machining operations generated by our DPP system. Each function block, especially the basic function block, can have multiple inputs and outputs and can maintain internal hidden state information. Different from the object-oriented approach, the behavior of a function block is controlled internally by a finite state machine whose operation can be represented by an execution control chart (ECC). The event flow of a function block determines the execution of an embedded machining operation. This means that a function block can generate different outputs even if the same inputs are applied. This fact is of vital importance for automatic cutting condition generation. For example, after a function block has been executed by a CNC controller, the execution of next function block can be very different depending on real-time machining events. Different machining parameters may be chosen and different algorithms may be triggered thus make function block execution (in turn, the machine itself) amazingly flexible and adaptive to dynamically changing machining processes.

Figure 5 shows how a function block-based application is generated for the case of pocket milling. Typically, the necessary milling information can be extracted from machining feature for pocket or retrieved from a know-how knowledge base for machining technologies. A well-defined control application has correct event and data flows among the function blocks. The event flow determines the sequence of NC operations. Events and data always flow into the left side of each function block, while generated data and events flow out on the right side. Applications comprising interconnected function blocks can be distributed to and executed one by one in machine controllers.

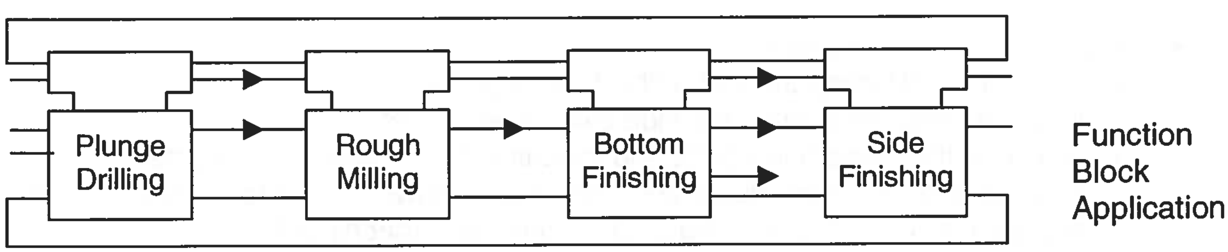

Figure 5: Function block application for pocket milling

There are a number of applications of function block in process control field, especially PLC devices, but from our literature review, there is not any case showing that function block has been used in manufacturing process planning, execution and monitoring areas. Therefore, the originality of function block application will be our most challenging task.

3.5.4 Web and Java 3D

Web based technologies are used extensively in this project. Most functional modules will be developed as independent components residing on multiple application servers.

An integral portal can facilitate all kinds of users to access the system within their authority using standard Web browsers.

For visualization and simulation of machining processes on the Internet, or for remote monitoring and control of networked machine tools and other manufacturing devices, we have to employ a technology that support:

- Real-time communication of sensor data and control commands
- Intuitive 3D environment for machining process visualization and simulation
- Easy manipulation of machines/devices through their graphical models

Interactive scene graph based Java 3D models are adopted in this project, especially in Task 5. Once downloaded from an application server, the Java 3D models are rendered by local CPUs and can work on behalf of their remote counterparts showing real-time behaviors for visualization at clients' sides.

3.6 Challenges

From the above discussions, the challenging issues exist in the DPP, utilization of function blocks, and shop floor integration. Following are some questions need to be answered while conducting R&D of this project:

- The implementation and demonstration of Distributed Process Planning concept.
  - What are the main features that distinguish DPP from traditional CAPP?
  - At what point should we separate SP and OP?
  - What factors should SP consider and how generic SP should be?
  - What are the steps OP should follow?

- The integration technology.
  - How can DPP integrate with scheduling system?
  - What are the mechanisms inside execution control?
  - How can the system integrate the machine level status and events?
  - What would the event flows and information flows be like for connecting main system functions (supply chain, shop floor and machine)?
  - How to maintain data and processes consistency among different systems?
  - How to streamline the decision-making processes as a whole?

- Specification and application of function blocks.
  - How to define machining features complying with function block specification?
  - How to define function blocks for different stages of process planning?
  - What can function blocks do in SP and OP?
  - Why choose function block as a means to integrate the system? What are the advantages?
  - How can the function block execute dynamically? What are the mechanisms staying behind?

4 R&D PROGRESS IN SYSTEM ANALYSIS AND PRELIMINARY DESIGN

In this chapter, we will briefly report on our system analysis and design work of the "advanced distributed planning and control in manufacturing" project.

4.1 System Outline - Node Tree and Node Index of IDEF0 Model

Task 1 (integral portal) and Task 6 (security issues) are among collaborative research efforts of this project that are considered as separate modules and can be integrated into the system easily later. At current definition stage, we will focus our attention on functional analysis of Task 2-5, because they are our responsibilities and contribute a lot to entire system functionalities.

The system analysis work is done using the IDEF0 methodologies. Figure 6 sketches the full system hierarchies on a single diagram as a node tree. There are two kinds of nodes: solid and hollow. The former represents a node that can be further decomposed to and represented as a more detailed page while the latter represents a leaf node.

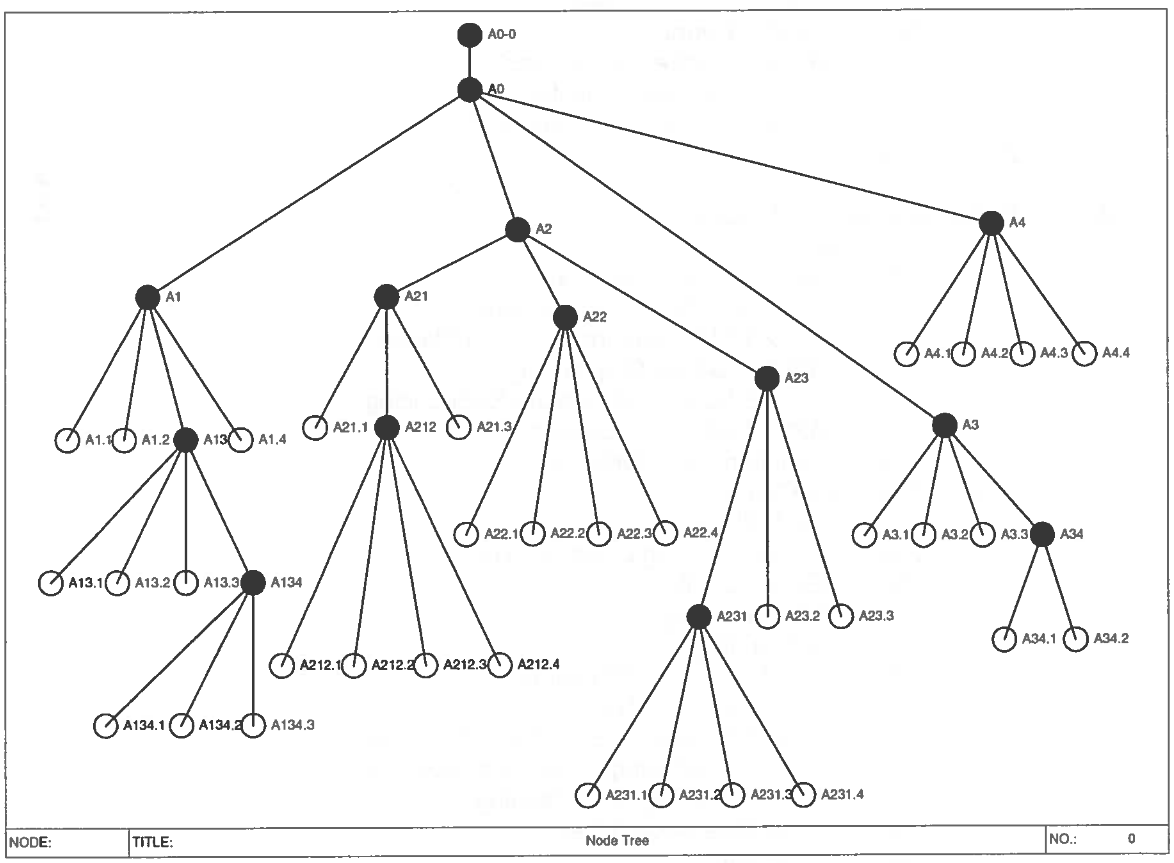

Figure 7: Node tree of system IDEF0 model

Because of the complexity of this system, the large number of nodes leaves no space to add text explanations. A complete node index, as an "outline" of node information, is given in Table 1. All node numbers, along with either diagram titles or box names, are presented in an indented form that exhibits the nested hierarchical structure of the model shown in Figure 6.

Both the node index and node tree represent the hierarchies of diagrams in the IDEF0 model. They are identical in content.

Table 1: Node index of system IDEF0 model

A-0	Advanced Distributed Planning and Control in Manufacturing (Context Model)			
A0	Advanced Distributed Planning and Control in Manufacturing			
	A1	Manufacturing Planning & Monitoring		
		A1.1	Order Decomposition	
		A1.2	Feature-based Design	
		A13	Main Manufacturing Planning	
			A13.1	Capacity Planning
			A13.2	MRP
			A13.3	Supply Chain Formation
			A134	Cluster Formation
				A134.1 Partners Searching
				A134.2 Partners Selection
				A134.3 Contract Management
		A1.4	Manufacturing Monitoring	
	A2	Distributed Process Planning		
		A21	Supervisory Planning	
			A21.1	Machining Feature Parser
			A212	Machining Sequence Generator
				A212.1 MF Grouping & Set-up Planning
				A212.2 Set-up Sequencing
				A212.3 Machining Feature Sequencing
				A212.4 Mfg Cost Calculation
			A21.3	Function Block Designer
		A22	Execution Control	
			A22.1	Task Planning
			A22.2	Set-up Merging & Dispatching
			A22.3	Event Handler
			A22.4	FB Monitoring
		A23	Operation Planning	
			A231	Local Operation Planning
				A231.1 Cutting Tool Selection
				A231.2 Operation Sequence Optimization
				A231.3 Machining Parameter Selection
				A231.4 Cutting Path Planning
			A23.2	Local Operation Scheduling
			A23.3	Executor
A3	Manufacturing Scheduling			
		A3.1	Scheduling Queue	

Table 2 lists reference notations used in the description of the IDEF0 model.

Table 2: IDEF0 reference notations

REFERENCE NOTATION	MEANING
2I1	Box 2 Input 1
O2	The boundary arrow with ICOM code O2
2O2 to 3C1 or 2o2 to 3c1	The arrow from 2O2 to 3C1 (The I, O, C or M may be uppercase or lowercase.)
I2 to 2I3 to 2O2 to (3C1 and 4C2)	From the boundary arrow with ICOM code I2 to Box 2 Input 3, through the activation of Box 2 that yields Output 2, to the availability (via a forking branch) of that output as Control 1 on Box 3 and Control 2 on Box 4.
A21.3C2	On diagram A21 in this model, see Box 3 Control 2. An embedded period means "look specifically at".
A42.3	On diagram A42 in this model, see Box 3.

For the clarity of modeling, we distinguish bold lines from regular lines. Bold lines stand for external relationships associate with the functions on a page. Generally, they are interfaces adapted from parent page. However, regular lines represent internal relationships within a page. They are not necessarily shown on the parent page.

4.2 System Model

A top-level context diagram (A-0) is shown in Figure 7, in which the subject of the model is represented by a single box (named after the same title as the project) with its bounding arrows. The input and output arrows in this diagram interact with functions outside the subject area and thus establish the model's scope and boundary.

Since the highest level of functions of this project is supply chain management, the enterprise boundary forms the interfaces of this system. Agent-base negotiation mechanism is adopted for multiple enterprises to form supply chains or virtual enterprise networks. The inputs of this system include mainly the information about orders, partners, bids etc. And the outputs include the information needed to be shared among enterprises, such as agreements, orders, product data, design data, plans, machining status, etc. The declaration of viewpoint in A-0 specifies that "information and functional assessment of the system" is what can be "seen" within the model context.

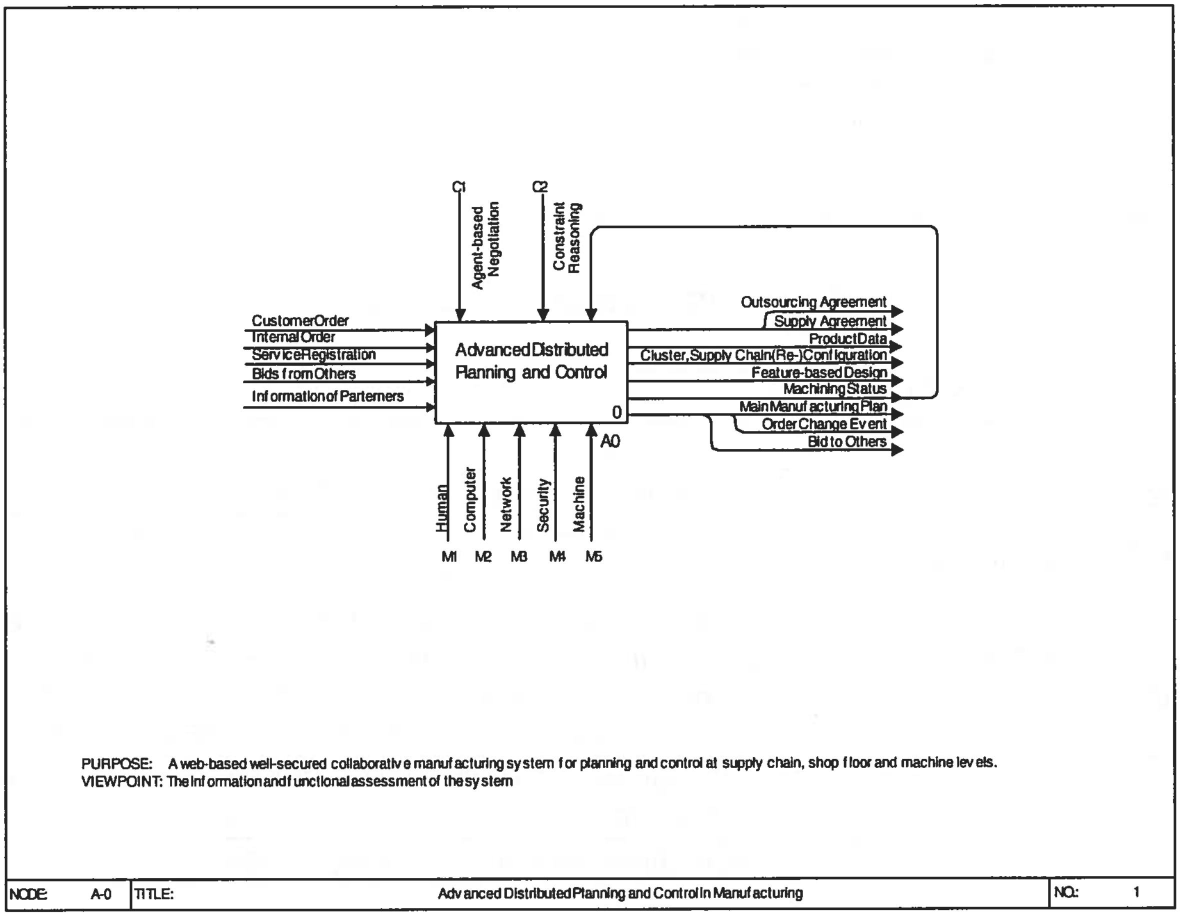

Figure 7: System context

A0 comes first in the system hierarchy, as shown in Figure 8. A1, A2, A3 and A4 represent Task 2 to Task 5, respectively.

Here, we use boxes standing for subsystems and arrows to represent relationships among these subsystems. Please keep in mind that the position of the four boxes does not represent any chronological or level-of-control concerns. For example, A2 locates up-left to A3, but it does not mean that DPP comes before scheduling. Actually, supervisory planning is done before scheduling while operation planning is after. Upon the level of control and management, A4 is a software system running at machine level (to monitor and execute the actual machining process) and A3 is a stand-alone scheduling system running at shop floor (for job task allocation). It is very hard to say which level that A2 belongs to. The supervisory planning and execution control handle the shop floor or enterprise level issues, whereas the operation planning doing machine level planning specification, optimization and execution. From this point of view, A0 is a "constraint diagram", which shows the specific interfaces that constrain each sub-function, as well as the sources and targets of the interface constraints.

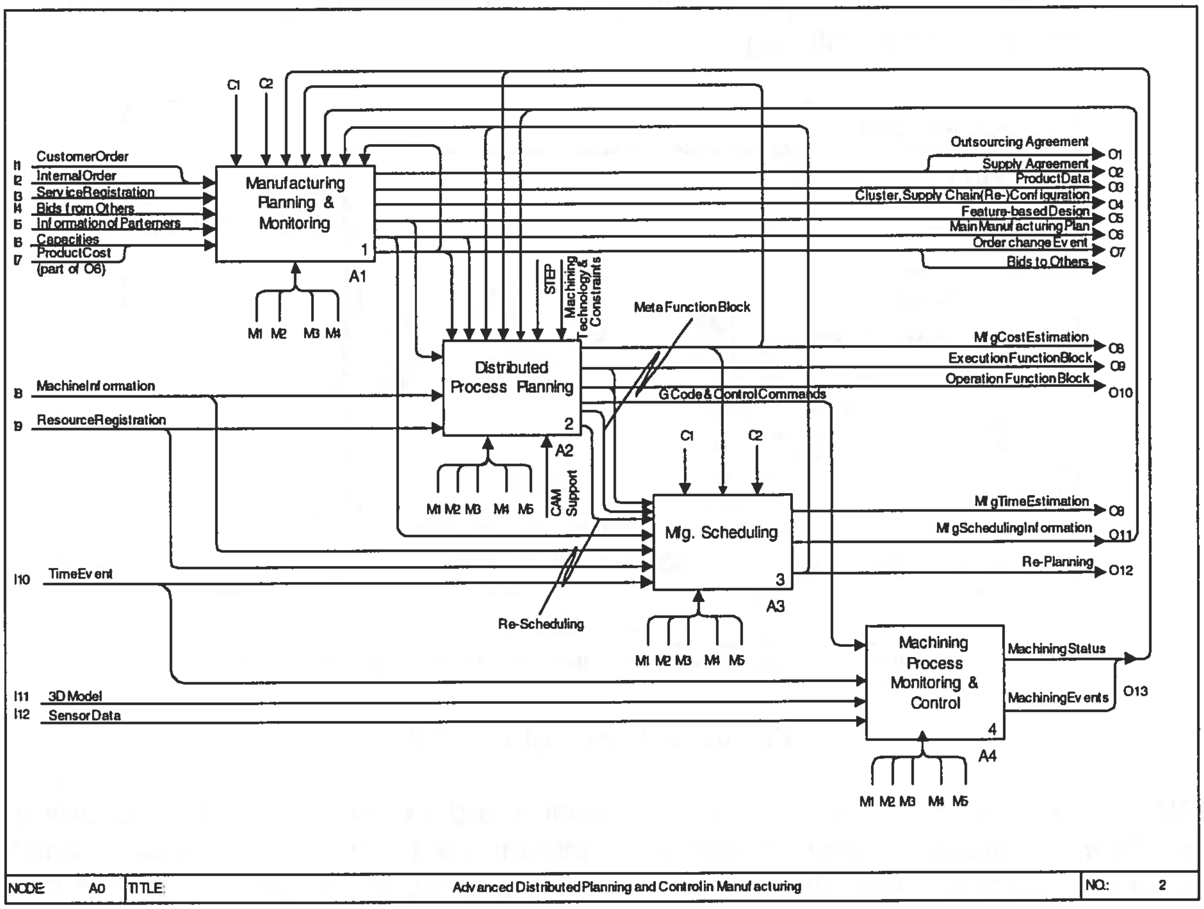

Figure 8: Distributed planning and control

4.3 Distributed Process Planning

A process plan generally consists of two parts: generic data (machining method, machining sequence, and cutting strategy) and machine-specific data (tool data, cutting condition, and tool path). A two-layer hierarchy is considered suitable to separate the generic data from those machine-specific data in distributed process planning [29]. The concept of DPP is illustrated Figure 9.

Other than SP and OP, machining features (M-Features) and function blocks are two crucial concepts adopted in DPP. They carry the machining process information and go through a number of functional modules of the system. As shown in Figure 9, M-features are first created and maintained as a part of the product data by the machining feature based design system (For non-machining feature based design systems, a third-party utility will be needed for M-features recognition). All the following process planning and control steps (including SP and OP) are based on M-feature information and their reasoning logics. The generic process plan generated from supervisory planning is packed into a set of function blocks and then dispatched to dedicated machine tool controllers. Function blocks can serve as a common language that both the (shop floor level) execution control and (controller level) operation planning can understand for process execution and monitoring.

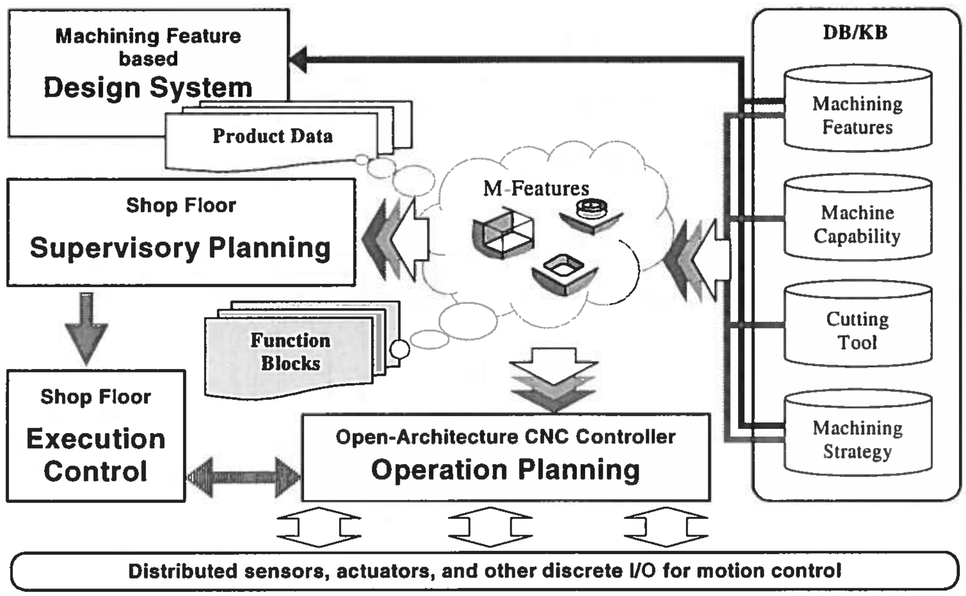

Figure 9: Concept of DPP

DPP system covers process planning/monitoring and execution activities occurring at shop floor and machine levels. It consists of three major modules: supervisory planning, execution control and operation planning. In this project, we neglect the feature-based design and feature recognition at product design stage, based on an assumption that machining features are already available in product data. They are either created directly by using an M-feature design system or recognized by a third party feature recognition solution.

4.3.1 Supervisory Planning

The supervisory planning (SP) module is responsible for generating high-level generic process plans. It consists of the following sub modules, each of which is described below in detail.

<u>Machining Feature Parser</u>

The recognized machining features are often insufficiently informative for process planning. During M-feature parsing, information required by the M-sequencing generation such as datum references, tool access directions, GD&T, precedence relationships, raw material geometry, and machining volumes to be removed must be identified or calculated. To distinguish from the original M-features, we call the output "enriched M-features".

Machining Sequence Generator

Machining sequence generation includes M-feature grouping and setup planning, multiple setup sequencing, and M-feature sequencing in each setup. The output of this module is a revised M-feature list, in which M-features are divided into a group of setups; both the setups and the M-features in each setup are properly sequenced. During the machining sequence generation, manufacturing constraints, datum dependency precedence, topological accessibility, and regular available resources are taken into account. Only prismatic workpieces for job shop discrete manufacturing are considered at this stage for proof-of-concept prototype development. The procedures for sequence generation are shown in Figure 10.

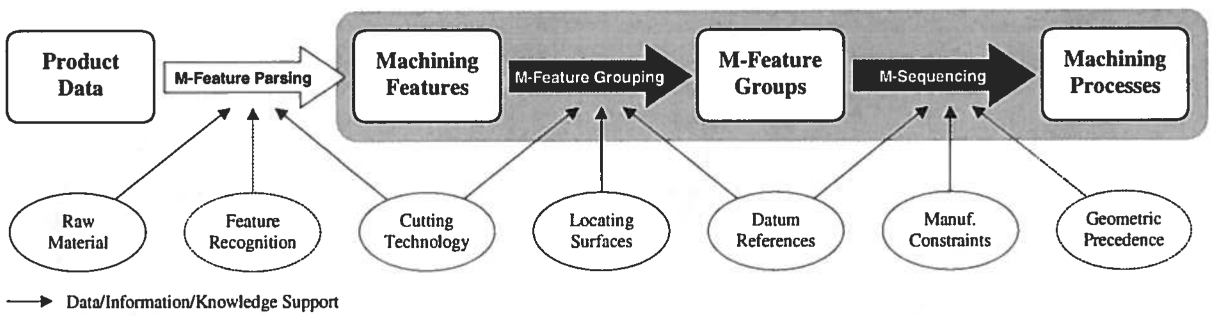

Figure 10: Feature-based reasoning for machining sequence generation

The research on DPP, particularly M-feature Parsing and M-Sequence Generation of SP, has been conducted by our group since 2002. Detailed research results will be reported in a separate master's degree thesis. Some results on this topic can also be found in our paper [30].

Function Block Designer

The generated machining sequence plans are sent to a function block designer, where M-features are mapped into appropriate basic function blocks. The output of this module is networked meta function blocks. Function blocks not only encapsulate the information, reasoning rules/algorithms about corresponding machining features and their fabrication processes, but also represent the complex sequence relationships and event handling mechanisms to facilitate the execution, monitoring and control of the M-features.

4.3.2 Execution Control

The module of Execution Control is shown in Figure 11 with the following functionality.

Task Planning

From common sense we know that the unit for actual machining and monitoring in manufacturing job shops is task, so that task planning is the first process in execution control. It creates manufacturing tasks based on enterprise level production plans, process plans of a product, and the task scheduling results. We combine the latter two types of information as one input, because in manufacturing scheduling, it already merged the original MMP information together with its scheduling result. The output is a set of function block network inherited from the meta function block template. A process plan of a product (MFBs) can be applied or reused every time a new task of the product enters the system. However, as task and sequence information are quite different in semantics and level-of-management, although it appears in the Figure 11 that they are in the same data object (we put only information as the output), they can be physically different objects (function blocks) with association relationships.

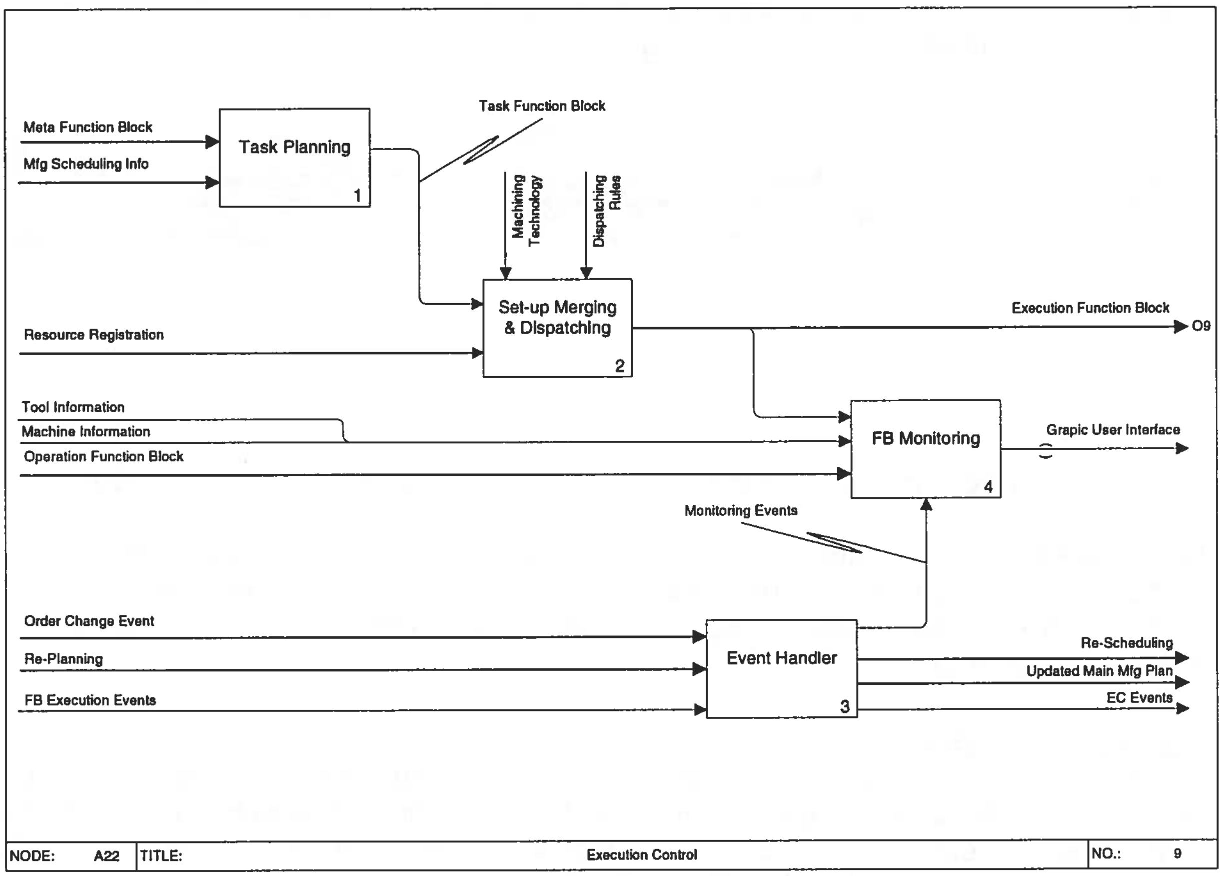

Figure 11: Execution control

Set-up Merging and Dispatching

After the scheduling system has given the result of task allocation, the general machining sequence that only considers regular resources can be further adjusted to fit specific machines. For example, in the case of a 5-axis CNC machine tool, two tasks (setups) of the same product assigned to this machine may have the chance of being machined by one single setup. Furthermore, the tool information can also be considered at this stage to do sequence optimization because a machine is already specified at this stage. The purpose of setup merging and sequence optimization is to make sure that the function blocks downloaded to a machine are reasonable. If the high-level sequence plan is too general and does not make sense to the machine, the OP will have to redo the feature sequencing again, which eliminates the advantages of our DPP concept over the traditional CAPP systems. We call the function blocks after setup merging process the "execution function block" to indicate that the generated function blocks now are ready to be dispatched to machines.

FB Monitoring

Function blocks provide a new solution for shop floor monitoring and control. This function block monitoring module is actually a graphical interface to users, from which all the status and events happening during machining processes can be displayed graphically on the screen. FB monitoring can monitor both the EFBs and OFBs. Most incoming events coming through event handler will cause FB monitoring module to change the graphical updates of function blocks. By introducing the concept of function block, monitoring and control can thus be done at each process unit rather than the task level (complete G code of a task) in most production management systems.

4.3.3 Operation Planning

Logics of operation planning are shown in Figure 12.

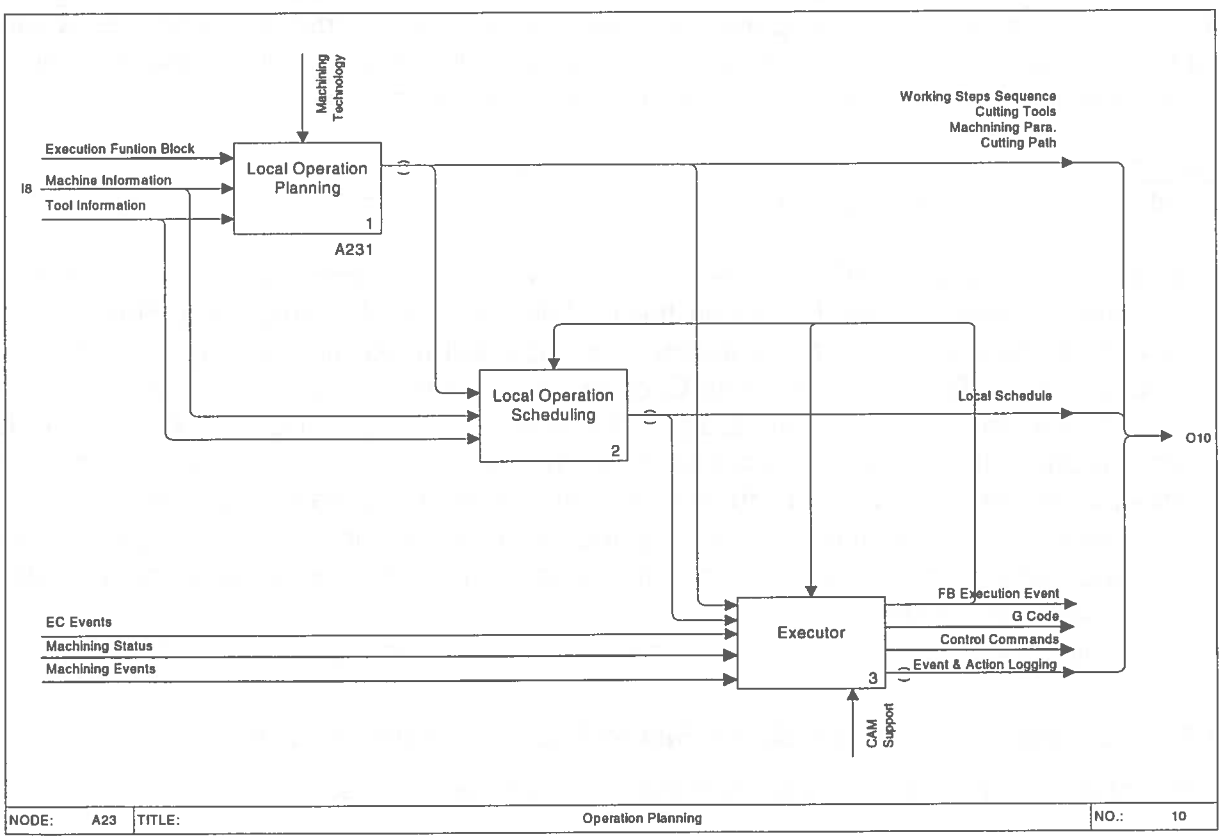

Figure 12: Operation planning

Local Operation Planning

For the EFBs downloaded from the execution control module, although their sequence information is already partially specified for the machine, the detailed steps required for final M-feature realization have not been completed at this time yet. Basic algorithms of machining strategies of M-features are encapsulated by the function block designer and run in this module to complete the plans by the specific machine controller. As a result, the resultant of operation function blocks deducted from the same set of EFBs may be different depending on the dispatching machines. This is one of the great contributions of object (function block) technology to the dynamism of DPP in the form of polymorphism. Tasks of local operation planning include assigning actual tool data, optimizing machining sequence with consideration of minimizing the change time of cutting tools, choosing appropriate machining parameters, as well as generation of actual cutting tool paths. As a controller is knowledgeable of the machine itself, it assures that operation function blocks for machining processes are locally optimized.

Local Operation Scheduling

The EFBs are not sent to the machine one by one on an execution basis. We suppose there are waiting lists of tasks with different lengths in front of machining centers. This module is designed for local task scheduling of the waiting list. The shop floor scheduling module does not have the authority to change the local schedules of a machine. If the local schedule cannot follow the schedules in EFBs (which are made in shop floor), it will create corresponding event to shop floor execution control. Execution control then activates the shop floor scheduling module to do re-scheduling. Machining events will also affect the result of local operation scheduling.

Executor

Functionalities of the Executor include:

- Execution engine of OFBs. OFBs are executed one by one by the executor in an explanation mechanism. Based on the real-time cutting dynamics (machining status & events) received from the machine, executor will make final changes to the next executable OFB and generate its G code for machining in a conventional machine tool. For example, if it is detected that the current cutting tool is very hot and under deformation, the executor is able to delay the execution of the next FB or adjust its machining parameters (i.e. reducing feed rate) to adapt to the new situation.
- Receiving bottom-up machining status and event, recording necessary logs in OFBs, making certain decisions for exceptions, and creating FB execution events to shop floor execution control.
- Receiving top-down EC events from shop floor and updating corresponding OFBs.

4.3.4 Summary of Function Block Based Shop Floor Integration

In this project, two important contributions are made, which are:

- The concept of Distributed Process Planning; and
- Function block as an integration means for manufacturing planning, scheduling, monitoring and execution.

4.4 Multi-Agent Scheduling and Integration

An agent-base intelligent scheduling system [20] will be integrated into this project to accomplish task assignments to machines and re-scheduling. The concept of this multi-agent scheduling system is shown in Figure 13.

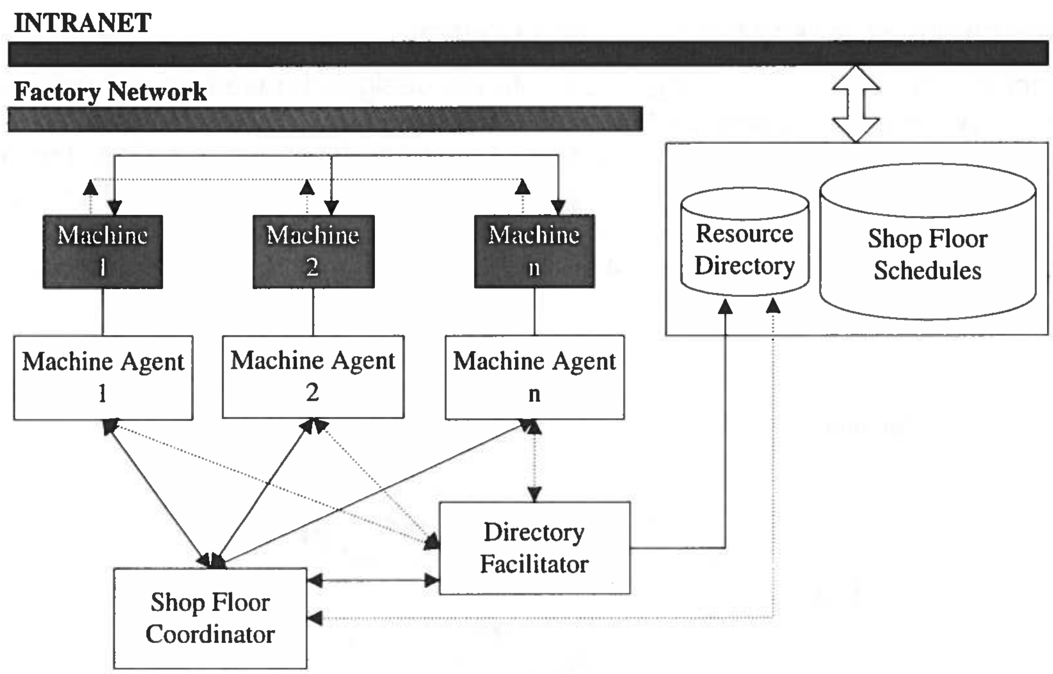

Figure 13: Agent-based intelligent shop floor scheduling system

All the Machine Agents (MAs) register with a Directory Facilitator (DF), who provides registration service for MAs, look-up service for Shop Floor Coordinator (SFC), and match learning service after task commitments. The SFC behaves as the dynamic scheduling coordinator of the shop floor that allocates time and operations to machine agents under its supervision. The scheduling process is generally realized through negotiation among agents. This system provides multiple agent negotiation protocols in order to adapt to different shop floor situations, such as Contract Net Protocol.

Since agent-based scheduling is ideal for dynamic shop floor situations but may not be optimized, a GA based algorithm is applied on top of the agent negotiation for dynamic scheduling optimization. Details of its structure and potential integration with *Wise-ShopFloor* are presented in a separate paper [22].

As described in [20], the agent-based scheduling system intended for implementing an open Internet-based distributed manufacturing scheduling and control in shop floors, which can be easily extended to enterprise integration. Such systems work in a dynamic world and keep pace with changes in real time.

A centralized scheduling optimization algorithm for all the unexecuted tasks (including all unscheduled tasks in the job list and the scheduled but un-dispatched jobs packed as EFBs) is recognized here and activated on a regular basis for the global optimization of scheduling result. The local schedules of tasks on machines are only checked at the resource-balancing step to evaluate the load of each machine. However, the whole shop floor manufacturing scheduling functionalities have no control of the local schedules of the OP.

4.5 Machining Process Monitoring and Control

The machining process monitoring and control is designed based on our existing *Wise-ShopFloor* (Web-based Integrated Sensor-driven e-ShopFloor) prototype system. This system provides users with a Web based collaborative environment for real-time monitoring and control of manufacturing devices in the shop floor. It utilizes the latest technologies, including Java 3D and Servlets, as enabling technologies for system design and implementation. Figure 14 shows how a Web based environment is linked to a real shop floor.

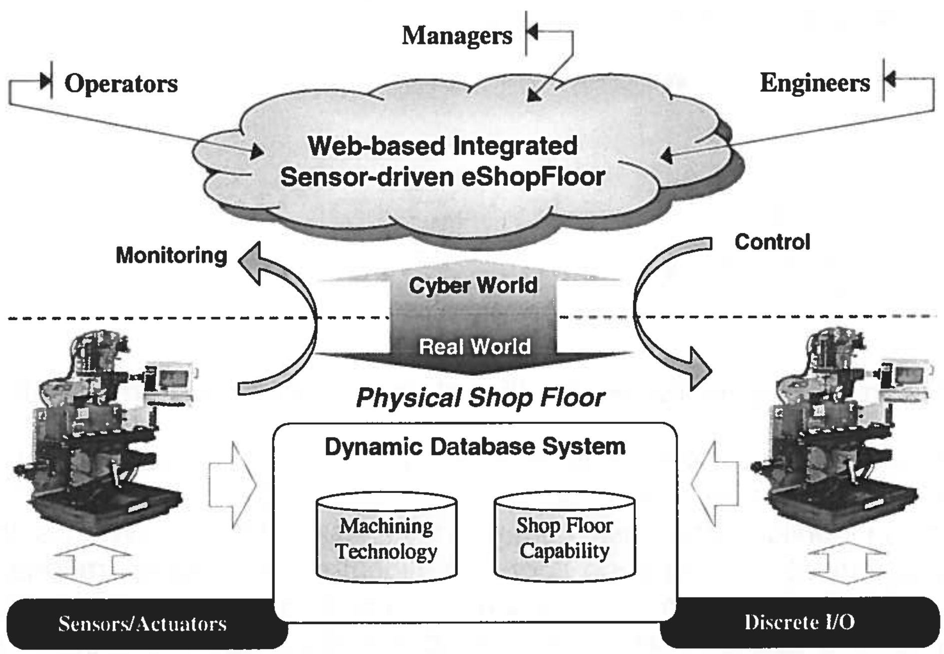

Figure 14: Concept of *Wise-ShopFloor*

The *WiseShopFloor* framework (Figure 15) is designed to use the popular client-server architecture and VCM (view-control-model) design pattern with built-in secure session control. The proposed solutions for meeting both the user requirements of rich visual data sharing and the real-time constraints are listed below.

- Using interactive scene graph-based Java 3D models instead of bandwidth-consuming camera images for visualization;
- Transmitting only the sensor data and control commands between models and device controllers for remote monitoring and control;
- Providing users with a 3D environment for shop floor navigation; and
- Deploying major control logic in a secure application server.

The *Wise-ShopFloor* functions as a visualization tool for machining process monitoring and control in this project. Its interfaces to physical machines (commander, signal collector, and signal publisher) can be reused for the integration with OP and execution control of DPP. Details of the *Wise-ShopFloor* can be found in [32].

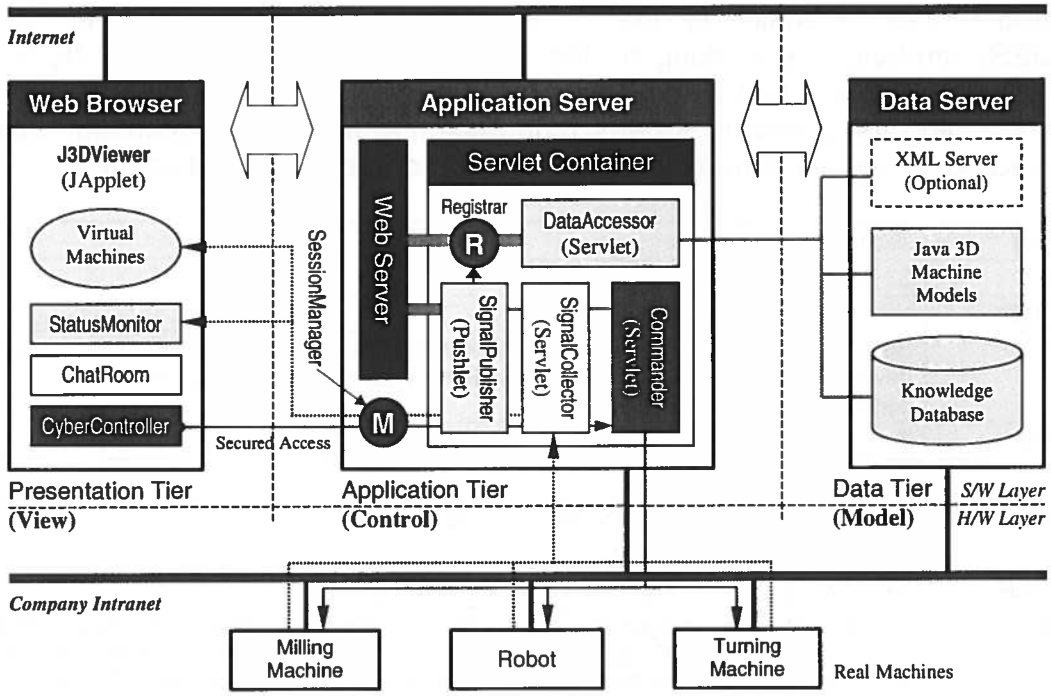

Figure 15: Three-tier architecture of *Wise-ShopFloor*

4.6 Security Issues

Security issues are the responsibility of NRC-IIT. The security and privacy related research work is currently conducted independently by the researchers at NRC-IIT. The results will be integrated into the system at a later stage.

Security infrastructures of this project will be reported separately by NRC-IIT.

5 SYSTEM IMPLEMENTATION PLAN

5.1 Distributed Process Planning

Distributed Process Planning is one of the major responsibilities of NRC-IMTI. Two UWO MESc students are working on the R&D of this module. Different from Task 2 (manufacturing planning and scheduling), this module focuses on low-level machining process planning for mechanical parts manufacturing in dynamic reconfigurable shop floor environment. An implementation plan of this module is outlined below.

Task Name	Technical Specification
Duration	33 days (partially completed)
Responsibility	NRC-IMTI (L Wang, W. Shen, Q. Hao)
Description	Suitable enabling technologies will be selected and a detailed technical specification will be developed. Reconfigurability of both machines and shop floors will be taken into considerations.
Deliverable	Technical specification

Task Name	Architecture Design of Supervisory Planning
Duration	25 days (partially completed)
Responsibility	NRC-IMTI (L. Wang, N. Cai) and UWO (H-Y. Feng)
Description	Architecture will be designed for this business module. Different from traditional centralized system, this module will use a specifically tailored two-layer decision-making structure. At SP level, functions are to be decomposed into software modules to conduct data parsing, machining sequence generation and setup planning.
Deliverable	Technical report on architecture design

Task Name	Setup Planning and Machining Process Sequencing
Duration	60 days (partially completed)
Responsibility	NRC-IMTI (L. Wang, N. Cai)
Description	Setup and machining sequence will be planned based on datum reference and tolerance requirements of a product. Maximum machining volume and machining feature based reasoning will be used for effective sequence planning.
Deliverable	Technical report and software prototype

Task Name	Function Block Design and GUI Implementation
Duration	90 days
Responsibility	NRC-IMTI (L. Wang, W. Jin)
Description	Function blocks are used to encapsulate machining process data and planning-scheduling integration. They will be properly defined and designed through a GUI interface.
Deliverable	Technical report and software prototype

Task Name	Operation Planning
Duration	150 days
Responsibility	NRC-IMTI (L. Wang) and UWO (H-Y. Feng)
Description	Machine specific data (especially the feed rate) will be generated and optimized at this stage by intelligent open CNC controllers. Tasks will be decomposed later.
Deliverable	Technical report on algorithms and implementation details

5.2 Planning and Scheduling Integration

Process planning and scheduling usually involve a large amount of decision-making across different levels along a product's life cycle. They are often interrelated. The objective of this module is to integrate those related planning and scheduling tasks at shop floor level, so as to achieve streamlined information flow. Future implementation details are outlined below.

Task Name	Methodology Development
Duration	43 days (partially completed)
Responsibility	NRC-IMTI (L. Wang, W. Shen, Q. Hao)
Description	Appropriate methodologies and technologies will be developed to integrate planning and scheduling at different levels (supply chain, factory, shop, and cell). Efficient and accurate communication between modules and users, and global optimization are the main objectives of this study.
Deliverable	Technical report on methodology and enabling technology

Task Name	Optimization Algorithm Research
Duration	88 days
Responsibility	NRC-IMTI (W. Shen) and UWO (H. Ghenniwa)
Description	This sub-module will be capable of finding global optimal solutions for resource planning and job scheduling, in terms of cost-effective factory operations in a dynamic shop floor environment. It will also be knowledgeable in optimal resource assignment if unpredictable machine failure happens.
Deliverables	Optimization algorithm and documentation

Task Name	Interfacing Technology with Other Business Modules
Duration	131 days
Responsibility	NRC-IMTI (W. Shen) and UWO (H. Ghenniwa)
Description	Synchronized data communication between high-level planning-scheduling module and low-level process planning module will be filtered and streamlined through these interfaces. Protocol issues will also be taken into considerations.
Deliverables	Inter-module interfaces and documentation

Task Name	Function Block Based Dynamic Scheduling
Duration	150 days
Responsibility	NRC-IMTI (L. Wang, W. Shen, Q. Hao)
Description	The utilization of function blocks in process planning and execution enables event-driven dynamic scheduling. This novel idea can link machine real-time status, job execution status, and unpredictable events into dynamic scheduling and process plan updating.
Deliverables	Technical report on methodology/algorithms

Task Name	Function Block Based Machining Process Monitoring
Duration	90 days
Responsibility	NRC-IMTI (L. Wang, Q. Hao, N. Cai)
Description	Service function blocks will be embedded into execution function blocks. These service function blocks are responsible for collecting events of job execution or the status of process plan completion. This sub-module enables engineers and shop managers to visualize their shop floor's real-time operation.
Deliverables	Software prototype and documentation

5.3 Remote Monitoring and Control

This module provides a Web-based solution for real-time monitoring and remote control that is found useful in distributed manufacturing environment. It will be able to provide real-time conditions (statuses) of shop floor equipment that can be used by other modules for process planning, resource scheduling, job dispatching, and dynamic re-scheduling. Different from camera-centric monitoring systems, this module uses sensor-driven computer graphics to achieve better network performance and flexibility. Shop floor execution control and device manipulation will also be facilitated by this technology. Implementation details are summarized below.

Task Name	Technical Specification
Duration	33 days (partially completed)
Responsibility	NRC-IMTI (L Wang, W. Shen, S. Lang)
Description	Based on literature review, suitable enabling technologies will be selected and a detailed technical specification for the module implementation will be developed. Portability and security issues will be addressed by the specification.
Deliverable	Technical specification

Task Name	Module Architecture Design and Implementation Approach
Duration	41 days (partially completed)
Responsibility	NRC-IMTI (L. Wang, W. Shen, S. Lang)
Description	Architecture will be designed based on the above technical specification for secured and efficient monitoring and control. Real-time constraints will be addressed. The architecture will be tailored specifically for relaxing network traffic delay and synchronized security control.
Deliverable	Technical report on architecture design and implementation

Task Name	Methodology Development
Duration	144 days (on-going)
Responsibility	NRC-IMTI (L. Wang, W. Shen, S. Lang)
Description	Methodologies and enabling technologies will be developed based on preliminary research results at NRC. Java 3D, XML, and Java Servlets will be used as enabling technologies for module implementation. Algorithms for secured data communication will be studied.
Deliverable	Detailed technical report on the methodology development

Task Name	Sensor Single Collection and Distribution Research
Duration	197 days (on-going)
Responsibility	NRC-IMTI (L. Wang, S. Lang)
Description	Enabling technology will be developed at server-side, being capable of collecting sensor data and distributing the data to the Web subscribers by using appropriate streaming protocol. The accurate data can be used for resource planning and task scheduling with other modules.
Deliverables	Methodology and documentation

Task Name	Remote CNC Machining and Device Manipulation
Duration	120 days
Responsibility	NRC-IMTI (L. Wang, S. Lang)
Description	Technologies will be developed to handle remote user's control commands with authentication and synchronization. By consulting with the *Session Manager*, only one user will be authorized to manipulate the same device at the same time.
Deliverables	Methodology, system component – *Control Commander*, and documentation

5.4 Cyber Workspace Prototype

This prototype will be built upon our existing preliminary system for real-time monitoring and remote control, as a single portal. Functionalities and a unique user interface will be developed and linked with other modules seamlessly. As a Web based solution, it will be well protected by the security and privacy module being developed by NRC-IIT. Our role in the prototype development is identified below.

Task Name	Communication and Negotiation Protocols
Duration	40 days (partially completed)
Responsibility	NRC-IMTI (W. Shen, L. Wang, S. Lang)
Description	A comparison study of related communication and negotiation protocols will be undertaken. Suitable protocols will be selected for detailed cyber workspace system design. Security concerns of Web-based data communication will be addressed.
Deliverable	Report on communication and negotiation protocols

Task Name	Multi-Party Negotiation Support
Duration	195 days
Responsibility	NRC-IMTI (W. Shen, L. Wang) and UWO (H. Ghenniwa)
Description	This task will implement technical support for multi-party negotiation during collaboration. Groupware technologies will be adopted for synchronizing communication through the cyber workspace. It will provide end users with a Web-based interface to interact with.
Deliverable	Negotiation Support module – *Meeting Room*

Task Name	Universal Interfacing Technology with Multiple Database
Duration	80 days
Responsibility	NRC-IMTI (W. Shen, L. Wang)
Description	A universal interfacing technology with different databases will be developed on server-side to facilitate multiple data accessing requirements from different business modules. It will also provide standard methods for data access and will be able to support connection pooling.
Deliverable	Data access module – *Data Accessor*

Task Name	Intelligent User Interface
Duration	120 days
Responsibility	NRC-IMTI (W. Shen, L. Wang, Q. Hao)
Description	This sub-module is to assist engineers to work efficiently by obtaining users' intent and providing information proactively. It is designed as a smart software module to track users' behaviors/habits and create appropriate profiles for users. This solution will be integrated to the portal for multi-user collaborations.
Deliverable	Software module

6 CONCLUSIONS

This technical report documents details of concepts, specifications, module architecture and interactions, problems and solutions, as well as current status and future work plans. It is intended to communicate among project team members and to log work-in-process. Only those modules that NRC-IMTI holds responsibilities are reported in details.

Machining features, agent technology, function blocks, and Java 3D are the main enabling technologies used for system implementation. Our contributions are the seamless integration of these technologies into our system, and the R&D of new architecture and algorithms. These novel ideas can be summarized as follows.

- Two-layer distributed process planning architecture that separates generic data from machine specific data to realize dynamism and responsiveness of generated process plans.
- Machining feature based reasoning that makes machining sequence generation and operation planning easy and straightforward.
- Function block based planning-scheduling integration that encapsulates machining data, monitors real-time execution of process plans, and triggers dynamic scheduling as needed in a real-time environment.
- Agent-based decision-making that enhances the system intelligence and responsiveness.
- Java 3D based approach that reduces network traffic and enables our system running in the Web-based real-time environment.

In the next project year, focus will be algorithm development and system module implementation. Java is pre-selected as programming language because of its platform independency and the ease of Web deployment. Judging from the partially finished modules/prototypes, it is evident that our approaches are advanced, practical, and promising in distributed manufacturing environments.

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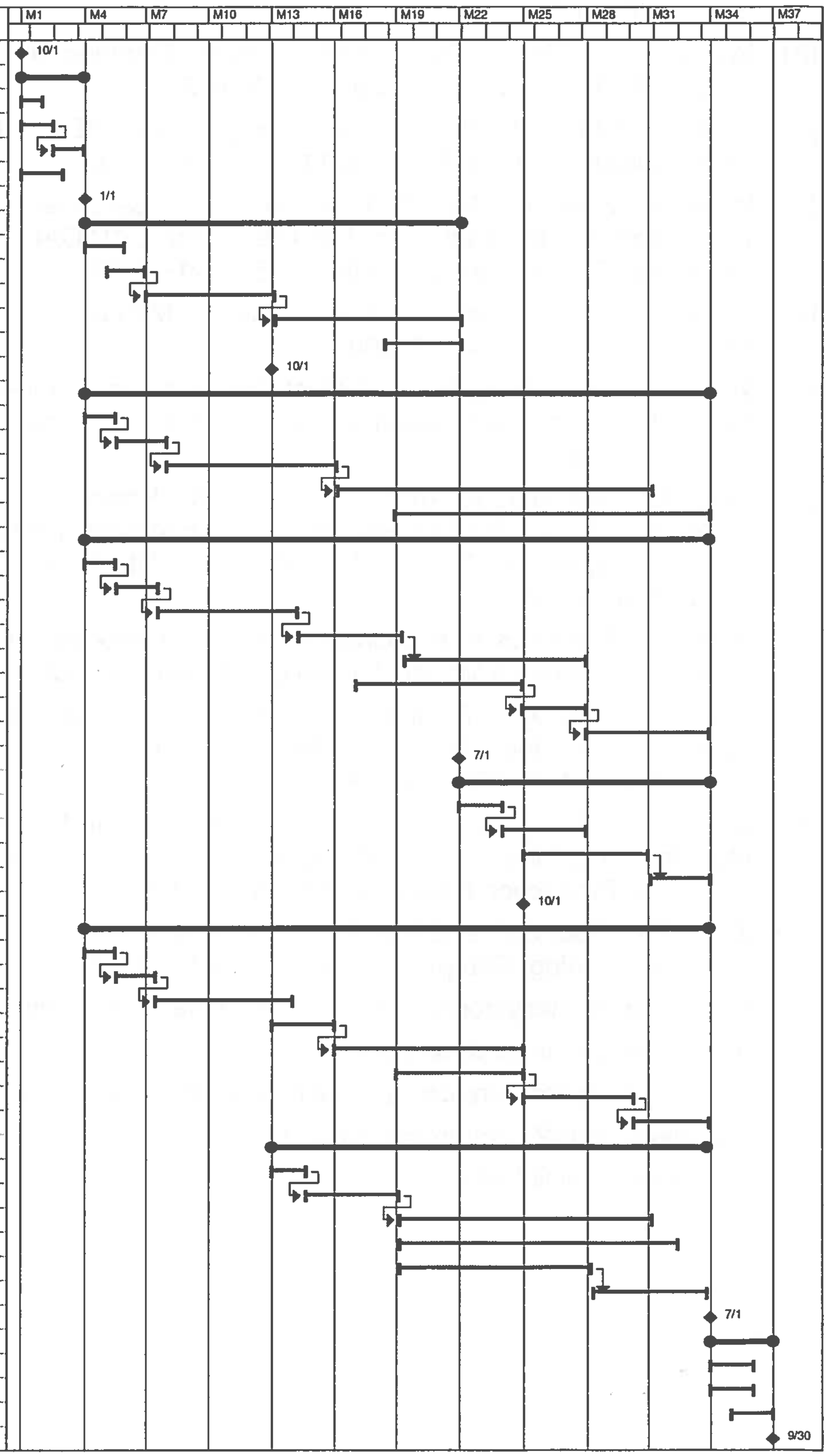
APPENDIX-1: OVERALL PROJECT SCHEDULE

ID	Task Name
1	***MS-1: Project Kick-Off***
2	**0. Project Start-Up**
3	0.1 Background IP Audit
4	0.2 Market Analysis
5	0.3 Overall Architecture
6	0.4 Project Environment
7	***MS-2: Project Review***
8	**1. Cyber Workspace**
9	1.1 Architecture
10	1.2 Protocols
11	1.3 Security Control
12	1.4 Negotiation
13	1.5 Database
14	***MS-3: Platform Delivery***
15	**2. Planning/Scheduling**
16	2.1 Specification
17	2.2 Architecture
18	2.3 Factory Scheduling
19	2.4 Supply Chain Planning
20	2.5 Factory Control
21	**3. Process Planning**
22	3.1 Specification
23	3.2 Architecture
24	3.3 Methodologies
25	3.4 Data Analyzer
26	3.5 Function Blocks
27	3.6 Agent-based Planning
28	3.7 User Interface
29	3.8 Module Testing
30	***MS-4: Module Integration***
31	**4. Integration**
32	4.1 Methodologies
33	4.2 Optimization
34	4.3 Module Interfaces
35	4.4 Module Testing
36	***MS-5: Module Testing***
37	**5. Monitoring/Control**
38	5.1 Specification
39	5.2 Architecture
40	5.3 Methodologies
41	5.4 Java 3D Modeler
42	5.5 Signal Collector
43	5.6 Remote Control
44	5.7 User Interface
45	5.8 Module Testing
46	**6. Security Support**
47	6.1 Specification
48	6.2 Methodologies
49	6.3 Confidentiality
50	6.4 User Preference
51	6.5 Security & Privacy
52	6.6 Trust Mechanism
53	***MS-6: System Delivery***
54	**X. Project Wrap-Up**
55	X.1 Deployment
56	X.2 IP Settlement
57	X.3 Final Report
58	***MS-7: Project Completion***



APPENDIX-2:

行政院國家科學委員會專題研究計畫成果報告

先進分散式製造規劃與控制之研究 (1/3)

計畫編號：91-2213-E-002-111
執行期限：91 年 8 月 1 日至 92 年 7 月 31 日
主持人：周雍強 ychou@ntu.edu.tw
國立台灣大學工業工程所

一、中英文摘要

企業內的生產決策通常是集權的形式或有明顯主從關係，而供應鏈網路內廠商之間的關係通常錯綜複雜，決策有分散式的特色。企業內與企業間的決策整合有基本性質的差異，供應鏈世紀的對生產決策的方法與工具有新的研究需求，本計畫以半導體製造供應網路為對象，研究協同規劃與排程的整合方法與工具。本計畫有三個研究工作：(1) 運算平台環境、(2) 制約與推理模式、(3) 效益驗證。本計畫將為期三年，第一年建置運算平台，並且建構雛形規劃模組。本文件為第一年的進度報告。

關鍵詞：協同規劃、生產規劃整合、供應鏈規劃與控制

Abstract

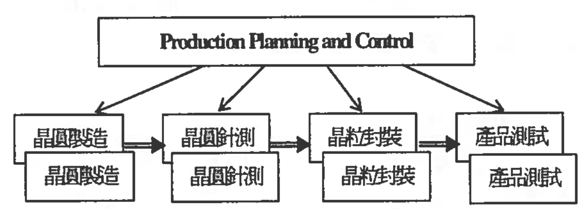
The performance of supply chains depends very much on the integration of business processes, decision-making and information systems. Compared with centralized planning, collaborative planning and scheduling is more natural in the distributed environment of supply chains. This project proposes to develop enabling technologies for collaborative planning and scheduling in semiconductor manufacturing. This project contains three tasks: developing a computation platform of planning and scheduling, developing models of constraint reasoning, and feasibility study and validation of benefits. This document is the first year progress report of this project.

Keywords: Integrated Production Planning, Collaborative Planning and Scheduling

二、計畫緣由與目的

企業內的生產決策通常是集權的形式或有明顯主從關係，而供應鏈內廠商之間的關係通常錯綜複雜，形成動態的網路，每個廠商的行為是受自我利益與目標所驅動，因此網路內的生產決策方式將與企業內常見的統制式決策方式不同，而有分散的特色。本計畫是中加的合作研究計畫，目的是發展虛擬製造所必需的協同規劃的方法與環境平台。台灣團隊的研究重點是供應鏈排程與工廠排程的整合，加拿大團隊的研究重點是製程規劃、作業排程、現場控制的整合。

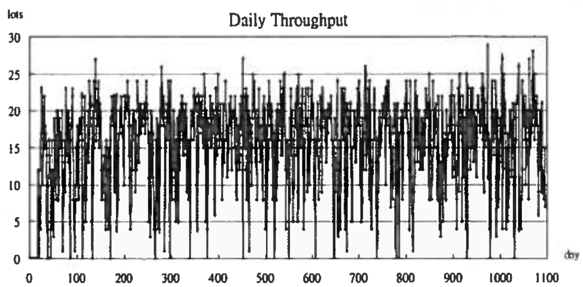
半導體製造的供應鏈涵蓋晶圓製造、晶圓針測、晶粒封裝、以及 IC 產品測試等。如圖（一）所示，每個製造階段都有多個平行工廠，並形成一個網路，工廠各有生產規劃與排程(PP&C)功能，然而要提升整體供應鏈效率，各工廠 PP&C 的功能整合是重要途徑。



圖一： 半導體製造的生產規劃與控制環境

圖（二）是晶圓廠模擬的一個結果（月產 11K wafers），由於機台當機、派工決策、績效要求等原因，晶圓廠的產出

非常不規律，在製品實際到達針測廠的時程往往與 PP&C 的預告時程有很大的差異，因此造成緊接在後的針測廠的生產困擾。如果在製批量或其到達的時程有很大的變異，勢必影響機台設定轉換的效率、機台使用率以及達交率，也會進一步影響到整體供應鏈的效率。



圖二： 晶圓廠產出的不確定性

整合生產規劃功能一般有三種的方式：
(1) 統制式(directive-based)
(2) 資訊透明化或分享
(3) 協同規劃與排程(collaborative planning and scheduling)

統制式整合係由強勢節點主導，弱勢節點配合。資訊透明化或分享是一般供應鏈常見的整合方式[4]。協同規劃則屬於規劃程序的整合。本計畫的研究主題為協同規劃與排程，目的是整合供應鏈節點間的生產決策。由於供應鏈的組織架構大致是分散式，協同合作是比較自然、符合市場經濟精神的整合方式，不僅成功的可能性較高，效益也較顯著。本計畫將以三年時間，以半導體製造為對象，研究分散式規劃的整合方法與工具。

三、研究方法

本計畫的研究方法是建構規劃與排程的運算平台環境、配以產業的製造數據、發展協同規劃方法並驗證效益。供應鏈係由許多工場節點構成，本計畫著重研究兩個節點之間生產決策的整合。這兩個節點可視為製造過程中的兩個階段，因此以下稱之為前階與後階工場。

本計畫的核心研究係以制約與推理模式做為協同規劃整合的中介。制約模式主要由三個部分組成：變數、值域和變數之間的制約關係[3]：

- 變數（variables）： $X = \{x_1, x_2, \ldots, x_n\}$
- 值域（domains）：變數值的集合 D_i
- 制約條件（constraints）：變數值必須滿足的條件。

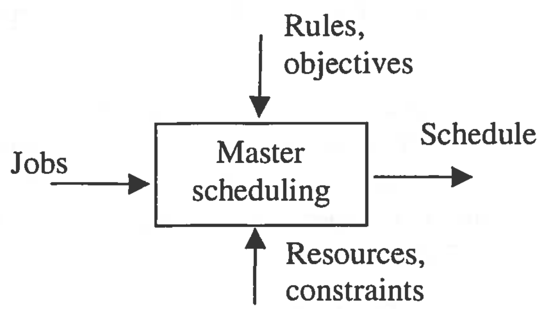
本計畫將以制約條件為表達法，發展各節點生產決策間互動機制。本計畫的三個工作項目為：

- 建構運算環境平台
- 發展協同規劃與排程的方法
- 驗證效益

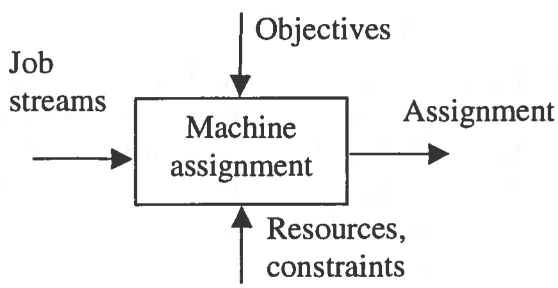
四、結論與成果

本計畫第一年進行建構運算平台以及雛形規劃模組。運算平台系統由三個部份構成：前階工場的生產規劃、後階工場的生產規劃、以及協同規劃模組。由於各節點工場都有許多生產決策，在供應鏈的層次主要會牽涉到總排程(master scheduling)與機台指派的問題。因此，本計畫研究載具的前階工場是一個 job shop，其生產決策是總排程（圖三）；而後階工場是非等效平行機群。一個機群內每個機台有其產能與機能(capability)的限制。機台分派是一個常見的問題，而分派的決策通常是依據機器的產能與機能、訂單交期與優先順序、設定轉換所需時間、製程要求、排程與管理效率的考量（如 machine pooling）、以及由經驗積蓄所產生的主觀偏好等等因素。本計畫以各工單的機台指派作為後階工場的主要生產決策（圖四）。

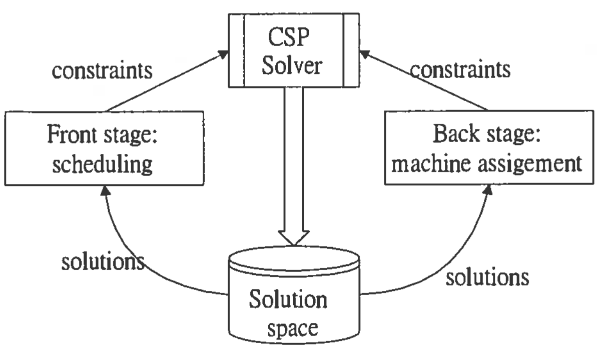
圖五爲以制約模式爲基礎的協同規劃架構。各節點提出各自的限制條件，再透過 CSP Solver 整合節點間的資訊，產生縮減的解答空間(reduced solution space)，各節點才再進行更進一步的生產決策。



圖三： 前階工場總排程決策



圖四： 後階工場機台指派決策



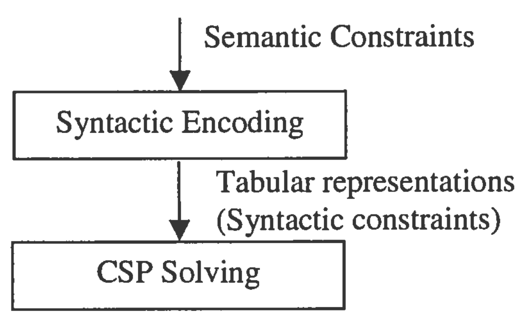
圖五： 協同規劃架構

在發展 CSP solver 的設計方面，本計畫的運算環境平台稱為 CSP solver，而核心的運算求解部份稱為 CSP engine。平台是使用 Java 執行環境配以 MS Access 資料庫軟體開發。在設計上，資料處理、轉換與儲存是 CSP solver 的功能，而 engine 力求精實。第一年首先分析機台分派與排程常見的限制條件的特性。這些條件包括：job preference, machine capability, machine capacity, multiple resources, alternative resources 以及 machine preference。對求解所構成的限制又可分為 ordering, domain, physical, conjunctive, 以及 disjunctive 等類別（表一）。

表一：語意的限制條件與語法的類別

Attribute / Type	Job	Job-Machine	Machine	Mach-Res
Job preference	Ordering			
Machine Capability		Physical		
Machine Capacity			Physical	
Multiple resource		Domain		Conjunctive
Machine preference		Ordering		Disjunctive
Alternative machine				Disjunctive, Ordering

CSP solver 必須具備各種限制條件的資料處理能力才能作為整合決策的中介工具。各種決策大多有其特殊的限制條件，這是屬於語意的層次，但是以 CSP engine 直接處理語意資料並不適宜，因此本計畫將語意與語法的資料處理分為兩個層次（圖六），語意編碼由 CSP solver 處理。不同決策的限制資料依據其語意需先編碼為表格形式的資料，這些表格所表達的語法就作為界定 CSP engine 機能範疇(capability)的依據。



圖六： CSP solver 之語意與語法層次

在整合規劃與排程方面，本計畫第一年發展一種基於優先等級配額的派工方法，做為調節多個製造階段間資源競爭的仲裁機制[5]。

本計畫第二年將繼續完成 CSP solver，CSP engine 以及決策模組整合設計，並進行效益驗證的實驗設計。

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