NIPPON STEEL TECHNICAL REPORT N0. 76 MARCH 1998

UDC 681 . 3 : 371. 048

System for Education and Training by Virtual Factory

Toshihisa YAMADA*[1] Shigeo KOSAKA*[1]
Eiji TASHIRO*[1]

Abstract:

An integral system for education and training, in which a production management system at an enterprise level through a mechanical processing system are included, has been constructed for the Advanced Polytechnic Center. Data associations between the upper and lower stages of a CIM function hierarchy and data associations between processes from the design process through the manufacturing process are merged seamlessly through a unified data base. Virtual factories, manufacturing lines, machines and measuring devices can be defined by simulation technologies of various kinds to allow a latitude in the content of education. The system has plural models of virtual factory, which will be effective for this Center making a future evolution of the operation of seminar.

1. Introduction

Electronics & Information Systems Div., Nippon Steel Corp. (hereinafter referred to as this division) has constructed, at the Advanced Polytechnic Center, an integrated FMS (flexible manufacturing system), that is an education and training system giving an extensive view of the next generation.

The Center is a public professional ability development facility founded by the Employment Promotion Corporation at the secondary Tokyo Metropolitan area center at Makuhari. In response to recent rapid technological innovation, the Center provides various kinds of seminars and technical support for the purpose of professional education and training to foster mid-level technicians at each enterprise (in particular leading medium and small-sized enterprises). A total of 65 Polytechnic Centers have been built throughout the country, and the Advanced Polytechnic Center, ranked at the top of these centers, is the core education facility of the Employment Promotion Corporation. It plays a role as an advanced technical accumulation facility, leading all the Polytechnic centers throughout the country.

This system is characterized by placing major emphasis on the information system as well as the conventional individual facility mainly in machine tools for education in mechanical processing techniques. Classes are conducted in a large classroom at the Center for constructing a factory model with full functions. The model factory is composed of a full layer system corresponding to seven layers of CIM (computer-integrated manufacturing) ranging from a top ranked production management system to a lower cell (workshop) controller for systematic linkage with machinery such as a mother machine and an automatic warehouse. The model factory enables construction of multiple virtual factories by various simulation without using actual machinery. The authors call the entire system a virtual factory (hereinafter referred to as VF) in a broader sense.

Using the VF as a training site, various seminars are operated for information application techniques such as including advanced cutting techniques and factory-wide management systems.

2. Entire System Structure

Fig. 1 shows the system structure for the major area. The factory introduced one each up-to-date five-axis and four-axis machining centers and one turning center with the capability of state-of-the-art cutting techniques. The management and control system for machinery such as the mother machine and automatic warehouse are composed of the following seven functions as shown in Fig. 1. They range from a product design function at the design technology department to a production management function and process management function at the factory production technology department.

*[1] Electronics & Information Systems Div.

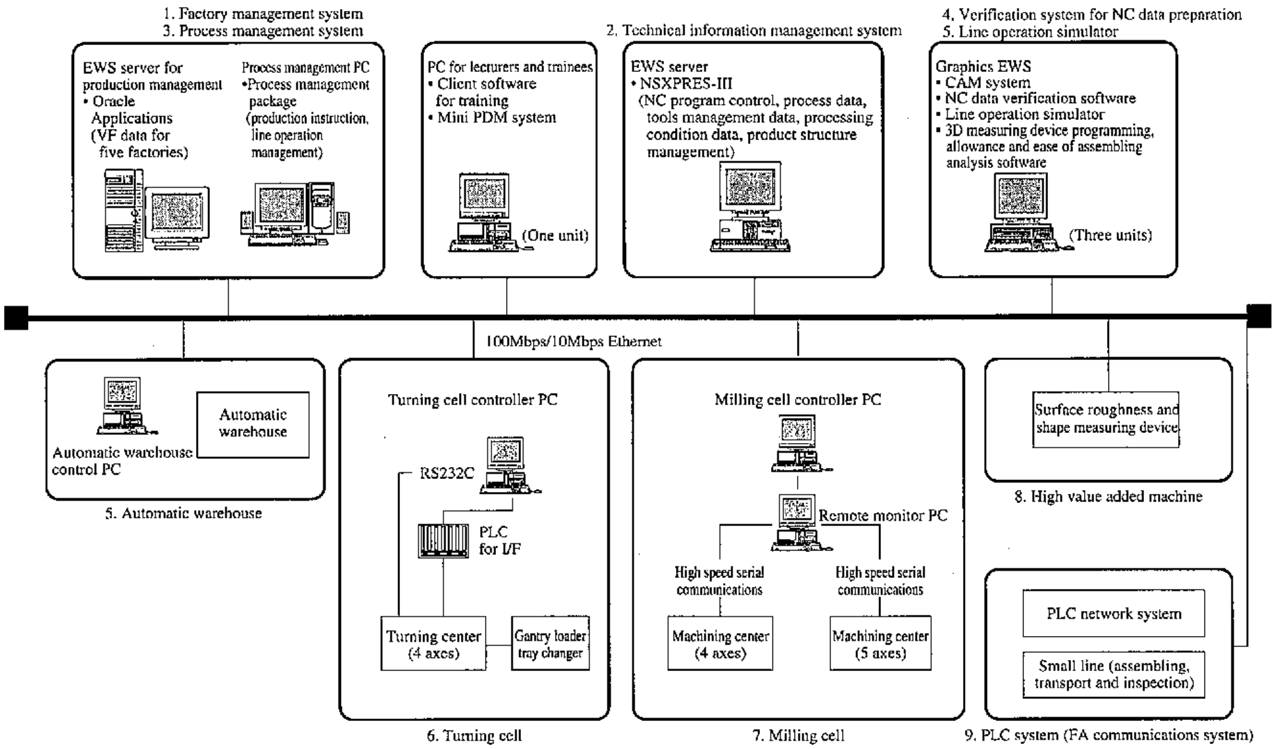

Fig. 1 Total system structure

1) Factory management system
2) Technical information management system
3) Process management system
4) NC data verification system
5) Line operation simulator
6) Cell control system
7) PLC (programmable logic control) system (FA communications system)

One of the concepts of this total system structure is a sharing of information among function layers and among processes within the same function layer, namely at ordinale and abscissa. This is realized by a system structure employing DOA (data oriented approach)[*1] to unify the database at all above layers to Oracle[*2] for unification and availability of the data.

2.1 Factory management system

The system is equipped for total factory management with ERP (enterprise resource planning)[*3] function. As the application platform for this function, Oracle Applications[*4], core product of this division, was employed.

The system has many function modules and established data models to restrict the need for customization. The major modules contain BOM (bill of materials), material production planning, material resource planning, capacity planning, inventory management, purchasing order, sales order, cost management, etc. In this system, several kinds of education data are incorporated for virtual experience of prospect production, and both order production and hybrid production. Education and training of the production management system are available in the virtual environment without operating actual machines.

2.2 Technical information management system

This function is intended to support and manage information necessary for processes ranging from the production preparation to production. PDM (product data management)[*5] was applied to the support system of the production preparation process. This enables the system to play the role of integrated technical database system with capabilities ranging from design to manufacturing processes by systematically managing not only drawing data in the design process, which is the advantageous field in the conventional PDM, but also various information on products and tools related to manufacturing.

NSXPRES-III[*6] with much experience in this division, was applied to this system. It is a PDM using the database of Oracle.

The above PDM is an enterprise level system; therefore, "mini PDM" applying the workflow at the personal computer level is also constructed for education of information share and application at the field level.

---

*1 DOA (data oriented approach): Also called data oriented design, this is an approach and concept for constructing information systems based on the data. The data to be managed in the enterprise are recognized as one of the important elements of management resources in the enterprise and are collected, analyzed, arranged, and integrated without being bounded by the framework of organization and business.

*2 Oracle is the trademark of ORACLE Corporation.

*3 ERP (enterprise resource planning): This is an approach and concept for integrally planning and managing management resources at the enterprise level including personnel, objects, and money for efficient management.

*4 Oracle Applications is the trademark of ORACLE Corporation.

*5 PDM (product data management): This is an approach and concept for systematically managing the component data of various information (drawings, documents, etc.) using products as keys.

*6 NSXPRES is the trademark of Nippon Steel Corp.

2.3 Process management system

This system has three functions: the management function of data specified for each facility (jig data, tool data, machine coordinates) in the Oracle database; the function to specify information on the lower controller according to the production schedule prepared by the process (production) design data and the production management system by virtue of PDM; and the function to collect resultant actual data.

2.4 NC data preparation and verification system

This system is constituted of the CAM (computer-aided manufacturing) system to prepare NC processing program based on the CAD data and verification function of the processing program within the workstation.

The CAM system has a post processor to produce the processing program for actual facilities of four- and five- axis machining centers and the turning center. The program verification system can define not only a material shape and a tool model but also an actual machine tool. This simulation can dynamically check not only verification of mutual operation between blades and works but also interference of tools and jigs. This enables complementing the checking function of the CAM system with a mere shape verification function.

2.5 Line operation simulator

The production management system is installed with the production planning scheduler for editing at the gantry chart. The simulator is a verification system that checks whether each production instruction prepared by this scheduler can flow in the actual line as planned or the process is blocked by a bottleneck. The simulator is a discrete simulator with a three dimensional modeling layout function for precisely modeling facilities actually installed at the classroom to define and verify correctly a work flow and human behavior in spatial and temporal aspects.

The simulator has not only actual facilities but also several kinds of virtual lines as an education model and is used for training to study productivity by time study and cost study and optimum layout of lines and cells.

2.6 Cell control system

A cell means a minimum unit of a function group that is focused on NC machine tools assembling peripheral equipment such as a conveyer and a work stocker. The delivered system has two cells, a milling center and a turning cell, as shown in Fig. 1. A cell controller is installed at each cell and has a function to control integrally machines composing each time by matching machine operation such as the production schedule and processing program prepared by the upper system.

2.7 PLC system (FA communications system)

The system has a remote monitoring function for the machine tools controlled by the cell control system, which is available for training of diagnosis of facility and failure. It has another small line for assembling, transport, and inspection independent of the main system and delivers the control programming by PLC not allowed by the machine tools on safety requirement. For a wide range of PLC control training, the system is equipped with a virtual simulation function for the control target.

In the past, each manufacturer's PLC system was a closed system, but this system applies a multi-vendor PLC system with ETHERNET*7 and data converter. The multi-vendor PLC environment provides a comparative training of various kinds of data such as PLC link, serial communications, ETHERNET communications, and radio LAN.

3. Data Flow in the System

Fig. 2 shows a schematic drawing of the total data flow. As mentioned above, the database is unified in Oracle, but individual Oracle may be used depending on function, characteristics, and scale of each application. Therefore, Fig. 2 indicates three Oracles for each layer in factory management, technical information management, and process management for data linked among Oracles.

3.1 Basic policy at data linkage

1) Using master information overlapped among multiple databases should be avoided for conducting data management based on the integrated database (assurance of data unification).
2) Production preparing information should be collected at the technical information management (PDM) system from which necessary data are delivered to upper and lower systems (clarification of data origin).
3) Data delivery should be carried out based on the system request each time (minimization of number of data accesses on demand request).
4) Facility specific information, entire tool information, and jig related information should be managed as unified information at the factory level (clarified global information).
5) GUI should be prepared for easy data maintenance (operating ability improvement).

3.2 Data flow

Data flow, as described in this section, ranges from design information as a data origin to processing information for facilities as a final point.

1) Registration of CAD information and preparation of processing information for facilities (product information registration)

First the NC program is prepared by the CAM system based on applicable parts drawings of constructing products and tool information, which is registered with drawing and tool information as an element of the product component information, a main function of PDM. Among product component information newly registered, processes required by integral conversion registration and the parts table management (BOM: bill of material) are also performed.

2) Preparation of product process information in PDM (process design)

Next, the processing process is constructed for each of the elements of the product component information. There is also the casting work for tools and jigs necessary for processing. PDM is available for viewing facility master information such as jig drawings and tool dimensions. **Fig. 3** shows this information system.

3) Preparation of facility information (work design)

The manufacturing process information prepared by PDM is converted for registration in each master table in the process management system and is managed with facility specific information of the process management system. The process management system receives the manufacturing plan prepared by the factory management system so that it can prepare and issue the specific work instructions.

The cell controller incorporates manufacturing plan and manufacturing information from the process management system based on the work instruction to specify at each machine tool's scheduled operation.

*7 ETHERNET is the trade mark of Fuji Xerox Co., Ltd.

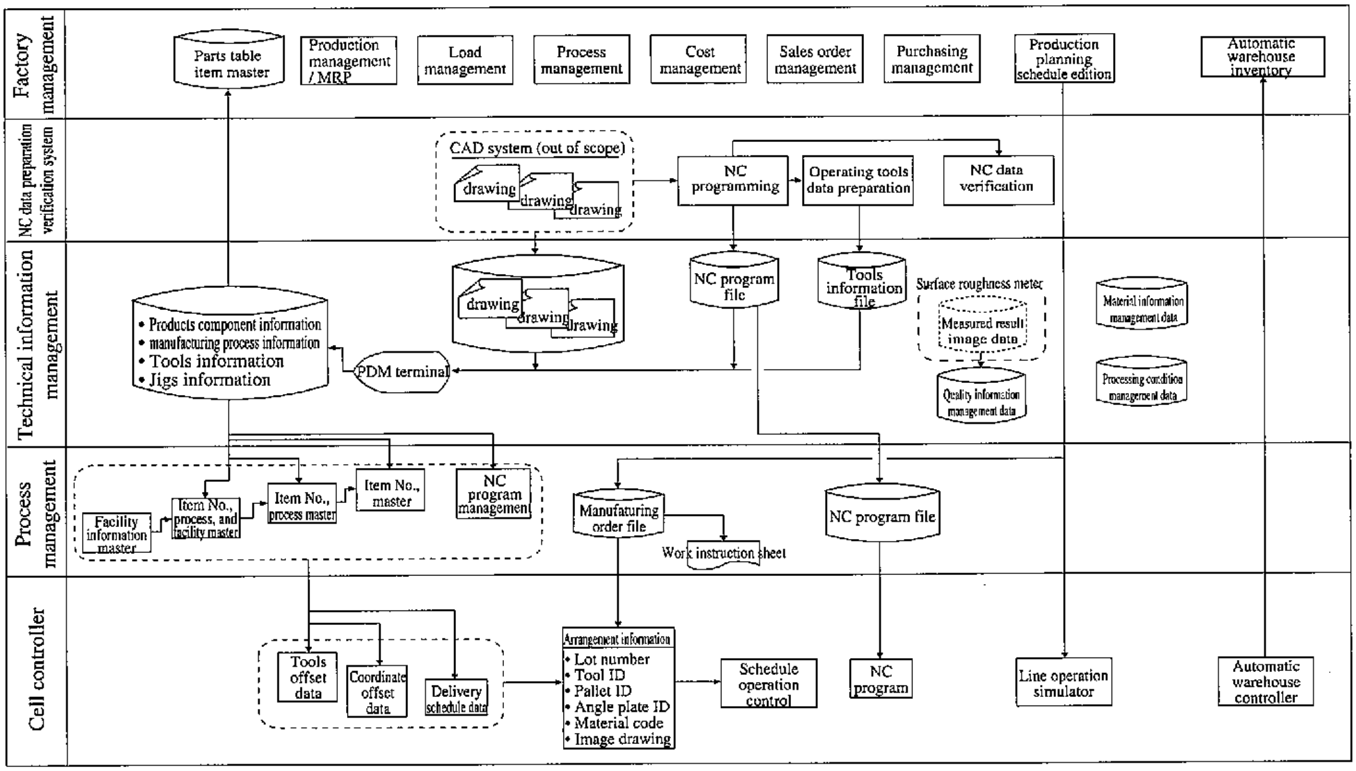

Fig. 2 Schematic drawing of data flow

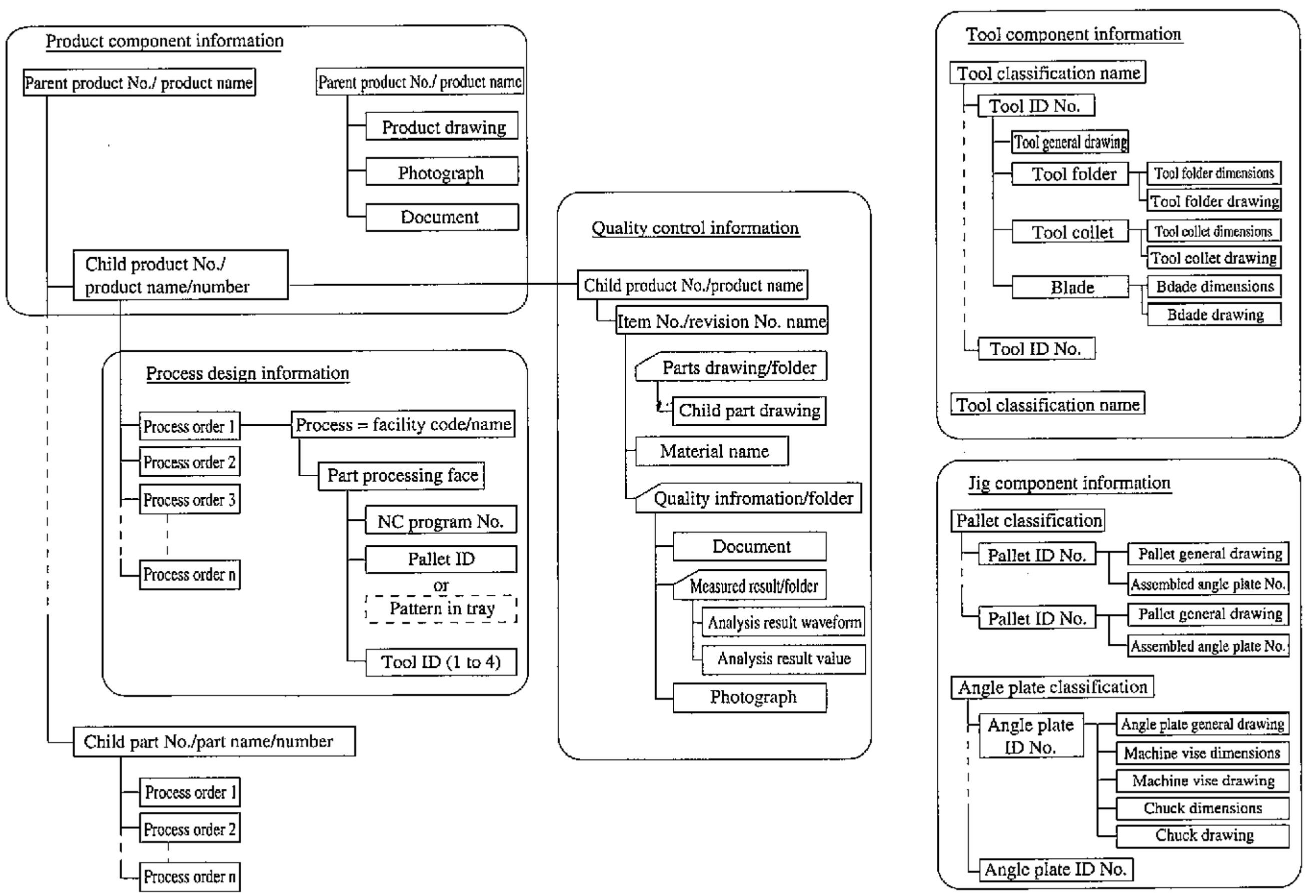

Fig. 3 Manufacturing information management system by PDM

4. Improvement of Process Design by Virtual Factory

Originally, mass products were produced from manufacturing instructions prepared by the process management system after establishing the manufacturing process. Therefore, the data flow described in the previous chapter is oriented to the process design work for constructing manufacturing methods for newly designed products. In fact, this is a repeated work process through many cycles of manufacturing design, trial manufacturing, and inspection. Our continuing target is to solve this by reducing this PDCA (plan do check action) by reducing the number of trial manufactures and thus shortening the period of development and increasing the quality of the products. This system proposes the following two solutions as measures and as an education and training system.

1) Definition of virtual facility by the simulator and its application to reduce trial manufacturing

2) Systematic management and share of design associated information by PDM

4.1 VF structure by simulator

CAE (computer aided engineering) has been carried out so far as a static analysis for each part based on CAD data. With recent CG technology and progress in hardware functions, simulation has been practical using virtual machines and virtual lines on computers. Characteristics of each simulator introduced and its application of manufacturing design flow improvement are described below.

4.1.1 Cutting simulator

Shapes of machine tools, tools, and jigs, and data on restricted motion can be easily modeled using built-in product libraries and taking CAD data. **Fig. 4** shows the defined five-axis machining center. This cutting simulator is not only able to execute NC programs prepared by the CAM system but also has a monitoring function of the machine's position, velocity, and acceleration as well as a geometrical analysis function for volume, area, center of gravity, and distance between two positions. This function is available for avoiding machine failure during trial manufacturing without thorough checking and is also available for the following simulation.

1) Verification of optimization of jig designs and work piece arrangement by checking interference between tools and jigs.

2) Reduction of cycle time due to changes in settings of velocity and acceleration and tool exchange.

4.1.2 Measurement simulator (off-line measurement programming)

After processing, it is necessary to measure whether a prototype is fabricated as shown in the intended design for feedback to the previous process. For complicated shapes, the three dimensional shape measuring equipment is applied, in this case the measuring program should be prepared to control the probe depending on the shape element and positions. The programming is carried out mainly by a teaching playback method, but this system constructed a measuring simulator for efficient off-line programming based on CAD data. The measuring program is verified for the virtual measuring equipment by the CG function similar to the cutting simulator. **Fig. 5** indicates an example of measuring the bore diameters.

4.1.3 Line simulator

The above cutting simulator and measuring simulator are used to simulate the relationship between a work and a cell. The simulators, if equipped with simulation function for facility line structure as a requisite, enables the checking of production efficiency at line input, the checking of time necessary for processing and measurement calculated back from the line restriction and target productivity, the checking of cross-over among cells, and it manifests involved problems to be improved. This gives an early judgement at the trial manufacturing stage so that important guidelines can be decided for the mass production stage. **Fig. 6** shows an example of the virtual lines.

4.1.4 Innovation flow of product design and application to education system

Fig. 7 shows a flow for making the best use of these simulators' characteristics in the conventional product design flow. Solid lines show the conventional information flow and the dotted lines show innovated lines. The dotted lines are not only for improving the conventional product design but they are also very effective

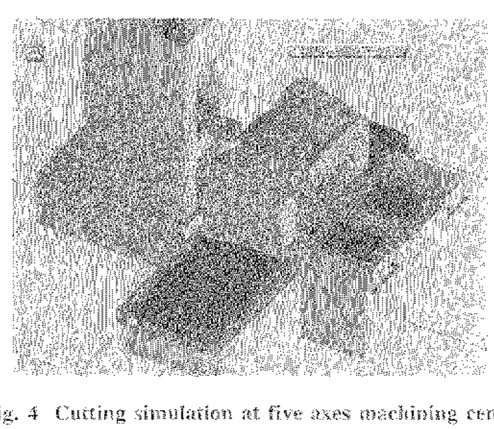

Fig. 4 Cutting simulation at five axes machining center

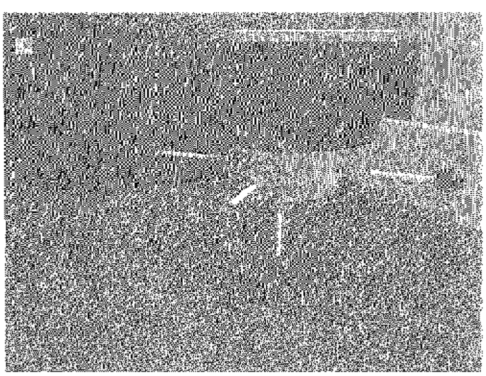

Fig. 5 Measuring simulation at three dimensional measurement equipment

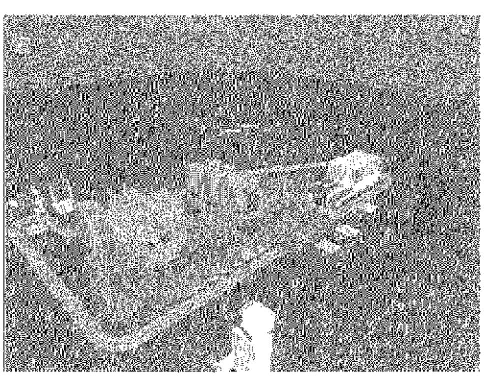

Fig. 6 Virtual line simulator

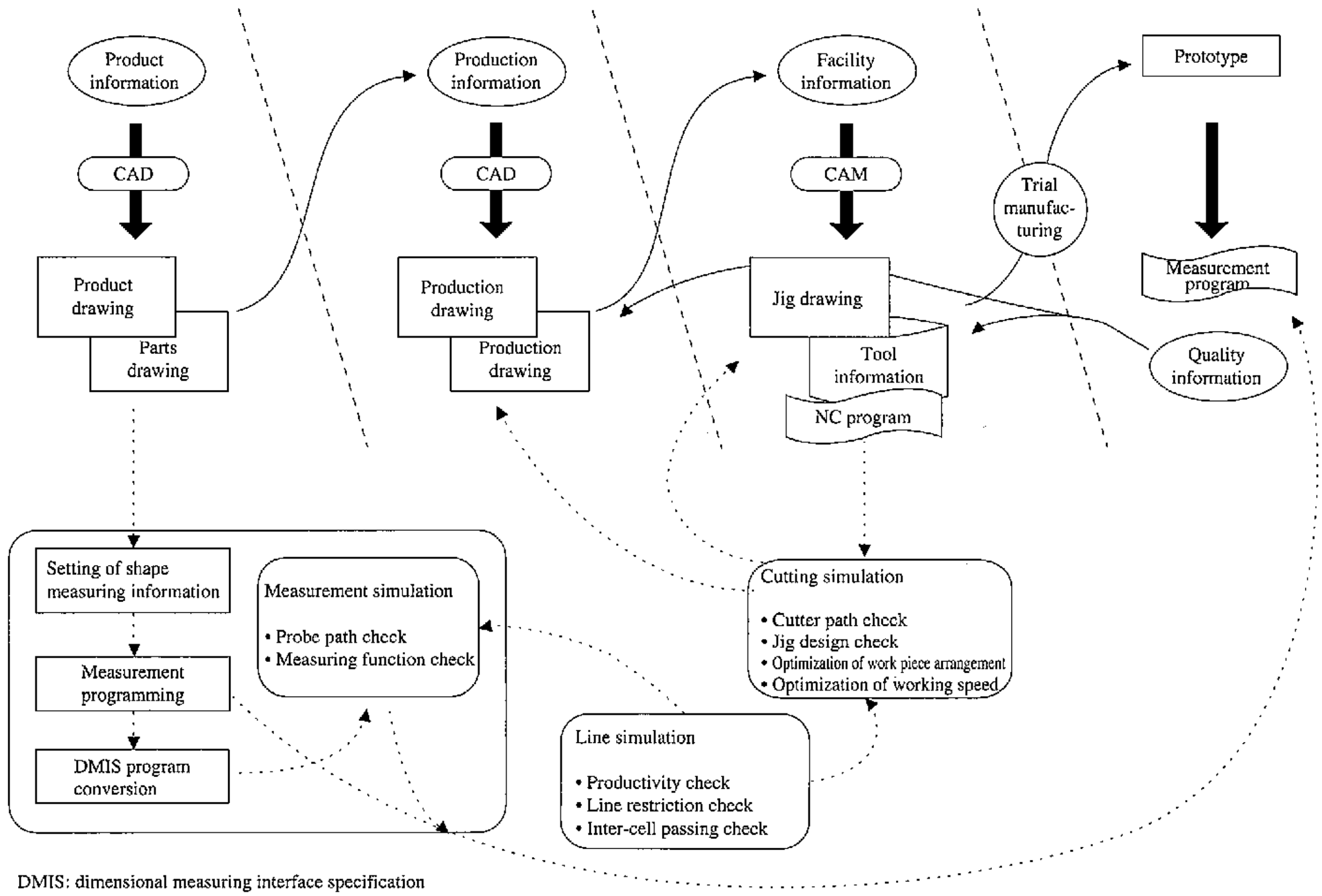

Fig. 7 Process distribution model from product design to manufacturing

as an education tool for product design from the viewpoint of employing multiple education systems in parallel by applying virtual machines and lines for avoidance of the failures.

4.2 Systematization of product design information by PDM

In Fig. 7, both conventional and improved flows are described, but they might not fully reflect the original design concept in a business flow based on drawings. In fact, it is very important to have a variety of information to describe in detail manufacturing drawings and data generated at the trial manufacturing stage each time, which are not written out and read out from each drawing.

This system, as mentioned above, employs a method for systematically managing information related to design and manufacturing by PDM. The information flow in Fig. 7 can be rewritten as shown in **Fig. 8**, in which the same database can be accessed from any point in the process to share information not divided by the process. This is also effective as an education system because many data related to design and manufacturing can be applied from the database.

5. Education Seminar Contents

Table 1 shows seminars scheduled by this system. During 17 seminars in the first year, VF will be applied in the seminars shown in No.1 through No.5 in the table.

6. Conclusions

In spite including of an education system, the system employs advanced information technology and machine process technology and is equipped with the foundation utilized in the seminars at the Advanced Polytechnic Center for the past five years. It also has various technical elements ranging from an enterprise level production management system to a processing system with environment suitable for various education and training activities.

In particular, the VF structure using the simulation technology has incomparable characteristics. For this technology, a digital mockup[*8] and a digital factory[*9] have been noted recently, mainly in the CAD/CAM world. This system realizes the same function not only in the design information but also in manufacturing information, in which these data are integrated through the unified database from design to manufacturing, thus making a seamless environment.

Technological development speed is remarkably rapid. We are determined to create an education and training system in which advanced technology and knowledge are effectively supplied to the trainees. Finally, we would like to thank many teachers at the Advanced Polytechnic Center and the people concerned for all their advice and cooperation for this system structure.

*8 Digital mockup: At the design stage, this allows realizing a product by precisely defining it on the display of a personal computer or a workstation using a computer graphic function instead of fabricating a full-scale model or a resultant output. It is applied as an object for various simulations.

*9 Digital factory: Same meaning as virtual factory. Virtual factory allows simulation of factory facilities on the display of a personal computer or a workstation using a computer graphic function. It is applied as an object for various simulations.

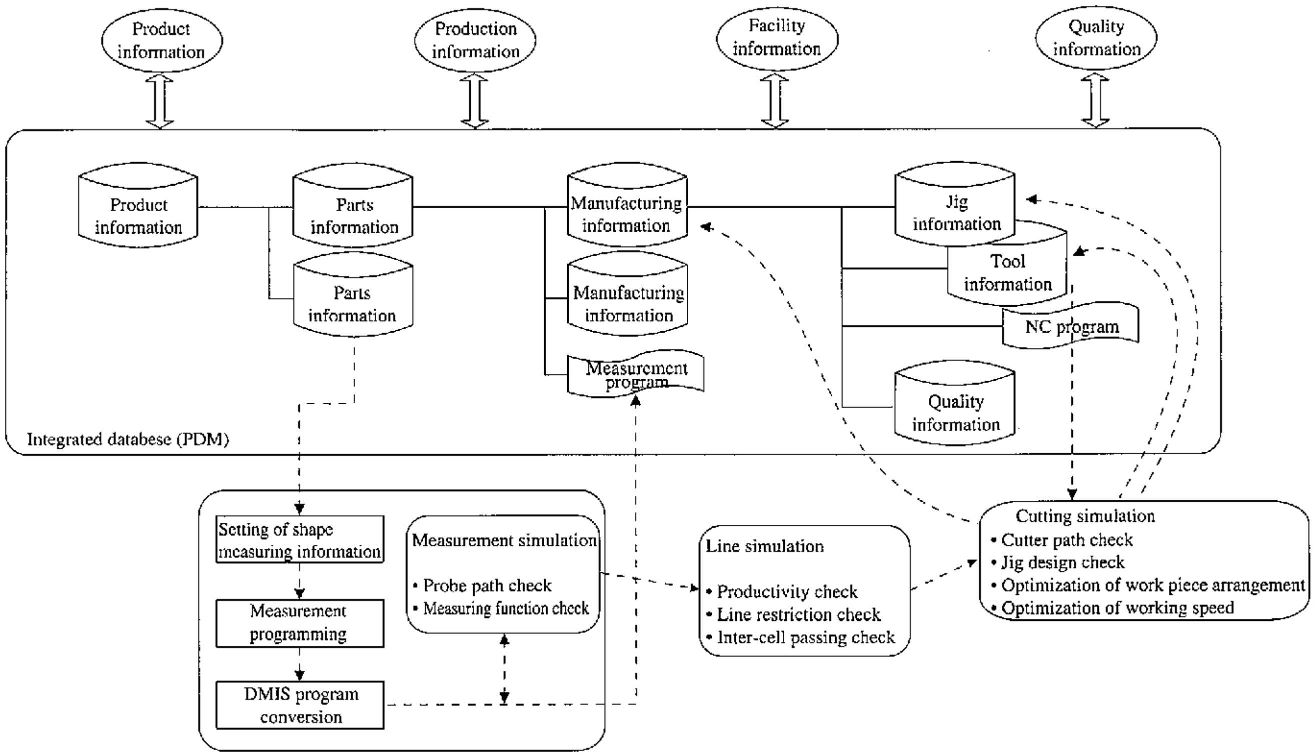

Fig. 8 Data link model from product design to manufacturing

Table 1 Seminar supplied by this system

No.	Division	Seminar title	Outline
1	Factory management	Computerized production management technology	What is production management ? production plan Direction of production control Response to limited production of a wide variety of goods, production plan
2	Technical information management	Accumulation of production know-how and its application	Informationalized processing site What is PDM? data input and using method Data for corporation's database construction
3	Technical information management	Informationalized site by a personal computer	Informationalized manufacturing industry, capacity of a personal computer Informationalized processing industry, customization
4	Verification of NC data preparation Line operation simulator	VF oriented production simulation technology	What is simulators? Line simulation Cutting simulation Simulation and real system
5	Verification of NC data preparation	CAM technology NC engineers should know	Outline of CAD/CAM, registration of processing information file NC data output, simulation, processing training
6	Verification of NC data preparation, cell	Cutting technology of NC lathe	NC programming Recent processing technology, machine operation training Integrated problem programming, processing training
7	Verification of NC data preparation, cell	NC processing technology CAD/CAM engineers should know	Outline of NC machine tool, required conditions by processing NC programming, DNC (direct numerical control) processing
8	Cell	Communications technology for NC engineers	Basic RS232C DNC software, local area network
9	Cell	Approach to efficient cutting	Cutting method, cutter path, cutting example, cutting blade
10	Cell	NC lathe multi-processing technology	Turning center, program Problem preparation, technical trend
11	Cell	Automatic macro	Macro variables, programming training Automatic measurement program Integrated problem programming, processing training
12	Cell	Cutting processing technology at machining center	NC programming review Programming considering additional axis Integrated problem programming, processing training
13	Cell	High speed technology at machining center	Present state of high speed cutting, customized high speed cutting Machine operation training Integrated problem programming, processing training
14	Cell	Present state and trend of fine processing technology	Fine processing technology
15	PLC/FA communications	Communications technology for systematization of factory facilities	Outline of communications, introduction of each communications method Confirmation processing of communications data
16	PLC/FA communications	PLC applying technology	PLC related device Connection between system component devices Model facility system operation
17	PLC/FA communications	Systematization technology by PLC	Connection of PLC to each device NC processing machine control, optimized control operation