S25-31

INTEGRATED FLEXIBLE MANUFACTURING PROGRAM FOR MANUFACTURING AUTOMATION AND RAPID PROTOTYPING

N93-22172

S.L. Brooks
C.W. Brown
M.S. King
W.R. Simons
J.J. Zimmerman
Allied Signal, Inc. - Kansas City Division [1]
Kansas City, MO 64141

ABSTRACT

The Kansas City Division of Allied Signal Inc., as part of the Integrated Flexible Manufacturing Program (IFMP), is developing an integrated manufacturing environment. Several systems are being developed to produce standards and automation tools for specific activities within the manufacturing environment. The Advanced Manufacturing Development System (AMDS) is concentrating on information standards (STEP) and product data transfer; the Expert Cut Planner system (XCUT) is concentrating on machining operation process planning standards and automation capabilities; the Advanced Numerical Control system (ANC) is concentrating on NC data preparation standards and NC data generation tools; the Inspection Planning and Programming Expert system (IPPEX) is concentrating on inspection process planning, coordinate measuring machine (CMM) inspection standards and CMM part program generation tools; and the Intelligent Scheduling and Planning System (ISAPS) is concentrating on planning and scheduling tools for a flexible manufacturing system environment. All of these projects are working together to address information exchange, standardization, and information sharing to support rapid prototyping in a Flexible Manufacturing System (FMS) environment.

INTRODUCTION

As industry strives towards a Computer Integrated Manufacturing (CIM) environment, many technological advances, such as computer aided design systems and computer controlled production systems, have been accomplished. However, these advances have created many islands of automation in which integration between these areas is still a labor intensive effort. As a result, an automated link must be established between the product definition and numerical control machines. The IFMP systems are knowledge based and reflect an open systems architecture. The projects are working together to develop an object-oriented database that houses a persistent representation of products, process plans, resource, NC, inspection, and other manufacturing support information. This integrated database will allow manufacturing personnel to share all essential manufacturing information in a common database, thus providing quick information access to the manufacturing community. The database will also allow concurrent processes to utilize the same information. The data structure within the database is an implementation of the Standard for Exchange of Product Data (STEP), an international standard. These data structures provide a standard format for information exchange inside and outside of the manufacturing facility. The IFMP systems utilize leading edge solid modeling technology and feature-base tolerancing to automate tasks that were impossible to automate in the wireframe world. Solid modeling and other leading edge technologies utilized within the systems open the door to meeting product requirements with a smaller fraction of money and resources and provide the capability to reprogram for quick production turn around of new product designs.

This paper presents a brief overview of the IFMP automation projects, how they are attempting to achieve interoperability and concludes with a description of the manufacturing environment these projects are being developed to support.

AUTOMATION PROJECTS

Advanced Manufacturing Development System

The AMDS system is a next generation product data translation and data management environment that is driven directly from international product data standards. AMDS embodies the technologies of distributed

1. Operated for the United States Department of Energy under Contract Number: DE-ACO4-76-DP00613

workstation database management, standard product data models, and high productivity object-oriented programming that will prepare KCD to adapt to the evolution toward open systems integration. Using AMDS , KCD has demonstrated that it can move files formatted in the emerging international Standard for the Exchange of Product Model Data (STEP) between commercial solid modelers and into a vendor independent distributed solid model product definition database. Using AMDS, KCD has demonstrated that it can transfer prismatic parts between three commercially available solid modelers. AMDS is used within the IFMP system as a transfer mechanism to move product definition from a client into the IFMP manufacturing database so that XCUT, IPPEX, and ANC can have concurrent access to product definition.

The AMDS architecture (see Figure 1) consists of two major pieces: a generator and a repository. The generator reads in an electronic form of STEP and automatically generates the repository which consists of an object-oriented database and in/out file translators for importing and exporting STEP ASCII files in standard format. The AMDS can be used in file exchange mode or applications can be written directly against the database. The AMDS generator guarantees that the database and its in/out file translators are consistent with each other. The repository is based on the ITASCA object-oriented database management system. ITASCA is a true object-oriented system and treats programs and data uniformly as objects. This uniform treatment of data and programs allows economies of programming that have greatly accelerated the development of AMDS software.

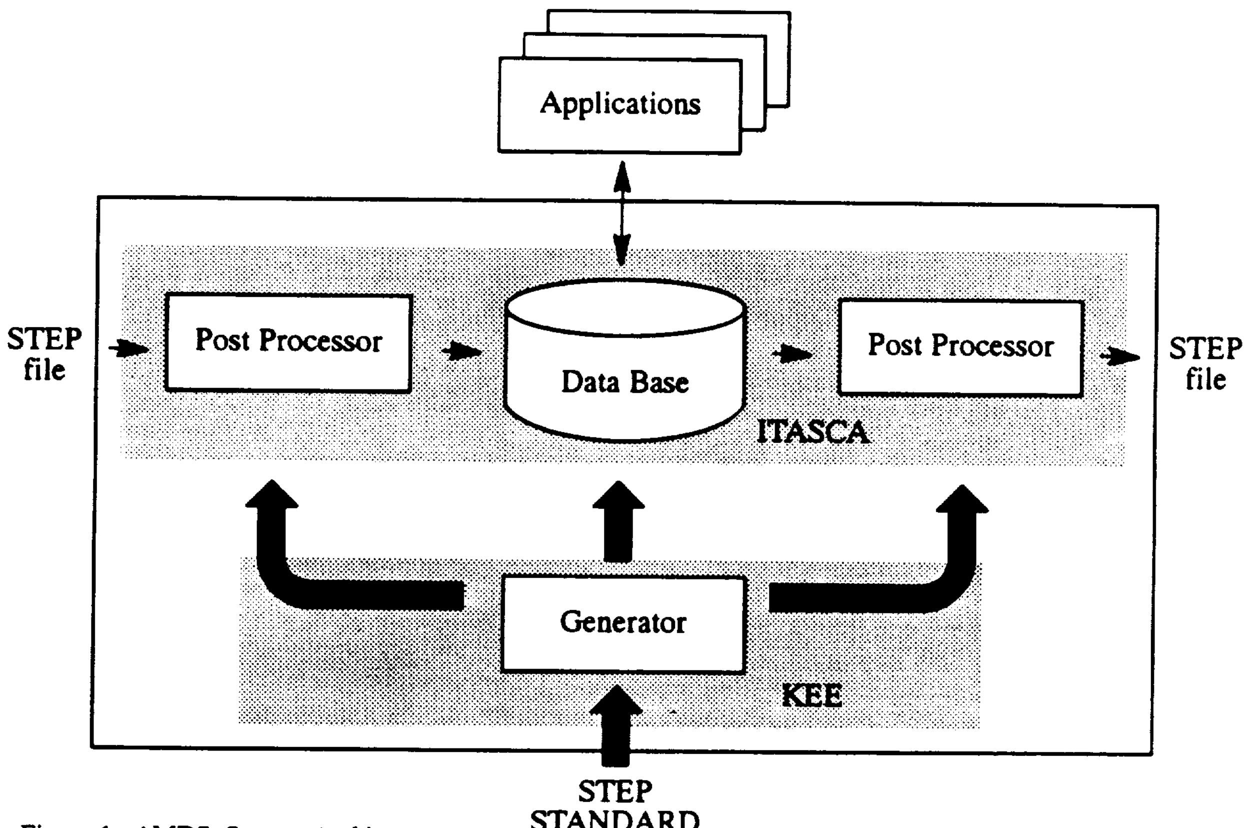

Figure 1. AMDS System Architecture

Expert Cut Planner System

A process plan is the sequence of operations necessary to transform raw material into a finished part. XCUT[1] maintains a persistent definition of products, and process plans in an object-oriented database. The information stored in the database is an implementation of the Product Data Exchange Specification (PDES), an international standard. XCUT incorporates the PDES models for product definition, geometric shape, form features, and process plans, among others. PDES data models specify the definitions of objects as well as an

ASCII exchange file format for transferring instances of those objects. Each object in the XCUT database has methods for storing and retrieving itself from the database and for reading and writing itself to an exchange file.

XCUT (see Figure 2) shares its object-oriented database with two other advanced manufacturing projects at the Kansas City Division, the advanced numerical control planning system ANC, and the inspection planning system IPPEX. All three systems will share the same information, providing seamless integration between process planning, NC, and inspection. Data modeling in EXPRESS-G and the EXPRESS language is used for defining objects and their relationships and attributes. The implementation of the database has been automated by a program that parses the EXPRESS files and generates C++ code and the database schema. The code generated by the parser produces all methods necessary for accessing objects from the database and for importing and exporting objects to data exchange files.

XCUT is linked with a solid modeling system to provide the spatial reasoning capabilities needed in process planning. The solid modeler provides visualization graphics and is used to identify the set of manufacturing features removed from the raw material to make the finished part. The definitions of all solid models used by XCUT are stored in its object-oriented database and are recreated in the solid modeler at run time.

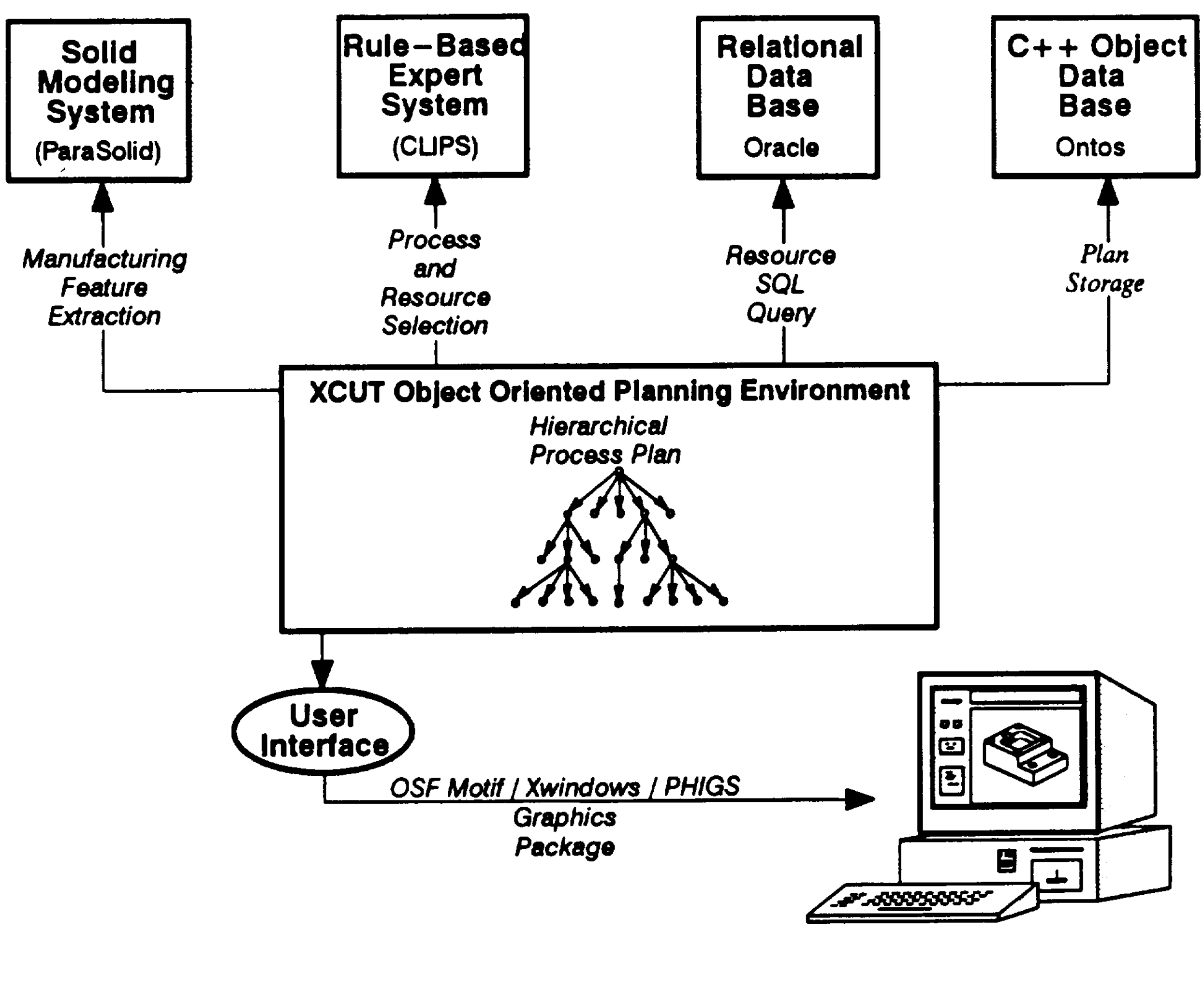

Figure 2. XCUT System Architecture

Advanced Numerical Control System

The numerical control (N/C) analyst's instruction set is embodied by a process plan. A process plan includes a sequence of the operations and processes necessary to transform raw material into a finished part[2]. The ANC system uses a process plan in an electronic form. The process plan is broken down into "bite sized" pieces that represent singular cutting tool operations or "single tool uses". A single tool use references one or many manufacturing features which provide the ANC system with design information describing the material to be removed. A sub-component of the manufacturing feature is a "delta volume". A delta volume is a solid model that provides a geometric representation of the volume of material to be removed. The manufacturing feature also includes non-geometric design attributes such as surface finish, tolerance, threads and edge conditions. Other information necessary for automation of N/C data preparation activities include machine tool characteristics, cutting tool characteristics, work holding devices and associated manufacturing resource information.

The ANC system (see Figure 3) uses an object-oriented database as a persistent repository for all of its information. An object-oriented kernel solid modeler provides the capability to answer arbitrary geometric questions algorithmically. The main component within the system is a solid model based manufacturing package. This software supplies solid model based toolpath generation capability. It also provides a user interface for viewing, manipulating and creating solid models.

"Knowledge based sub-systems are extremely important in the capture, reduction, packaging, expression and dissemination of the knowledge utilized in operating a manufacturing enterprise" [3]. The ANC system incorporates a knowledge based system to provide these capabilities. Manufacturing rules for this "system of experts" are being developed by a group of resident experts in the field of numerical control and process planning. An inference engine uses these manufacturing rules, along with the related part, machine and tool information to determine the appropriate feed rates, spindle speeds, depths of cut, step over distances and motion parameters required to generate an N/C toolpath.

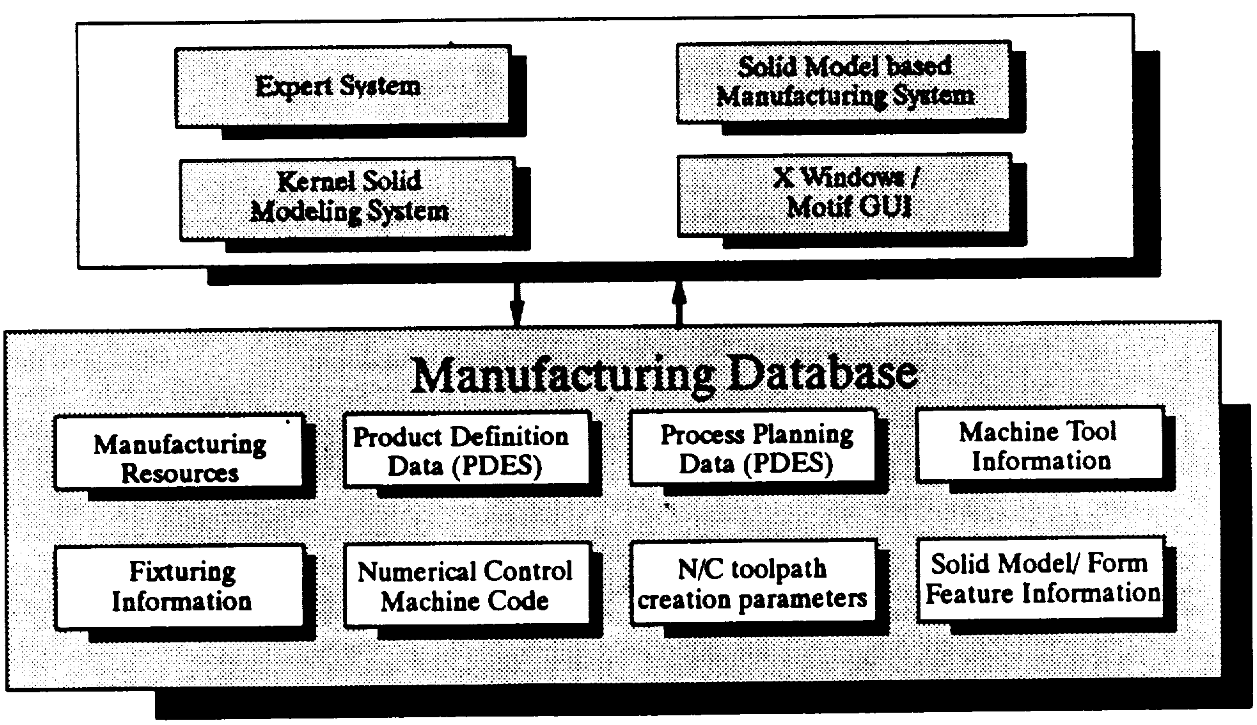

Figure 3. ANC System Architecture

The ANC system interprets process plans and analyzes supporting manufacturing, product and solid model feature information to determine appropriate motion controls for machining a part. The machinable volumes generated by XCUT are used as geometric input to the ANC system. The ANC system also utilizes process plans that are generated by XCUT. Solid models that represent the volume of space through which the cutting tool travels are generated for each single machining operation. These solid models are compared to solid models representing the fixture assembly to detect collision. They are also used to generate solid models that represent the shape of the part after a single machining operation is performed. These solid models (classified as In Process States) are used to verify the accuracy of the NC data, and to check for collision on entry motion for subsequent machining operations. The system also includes the capability to automatically regenerate NC data based on changes to the part design.

Inspection Planning and Programming Expert System

IPPEX (Inspection Process Planning EXpert)[4], is a knowledge-based system currently being developed for the dimensional inspection of piece parts at the KCD. The objective of IPPEX is to make CMMs more effective production support inspection tools by creating consistent and standard inspections, enhancing their productivity, and capturing inspection expertise. This is accomplished through applying product modeling, incorporating an explicit tolerances representation, establishing dimensional inspection techniques and embedding an inference mechanism.

The IPPEX system automates the generation of inspection process plans and part programs for measuring piece parts with coordinate measuring machines (CMMs). While the XCUT and ANC create plans and instructions for machining, IPPEX concurrently will create the appropriate inspection planning and generate the part programming code necessary for sample-point dimensional measurement[5]. The IPPEX inspection activities will integrate with the XCUT activity plan to create a final product process plan. Given the inspection scope, defined by feature-based tolerances in the product model, IPPEX will plan the sequence of operations necessary to verify that the manufactured part conforms to requirements. These operations will contain activity objects that will identify resources such as measuring machines, part set-ups, and probe configurations, and tasks such as establish datum reference frame, verify tolerance, and measure feature. The process plans will also contain inspection techniques based upon the feature's current measurement criteria. The inspection techniques determine the number of sample points, the distribution of these sample points, and the selection of the appropriate substitute geometry algorithm. Based upon this inspection process plan, a Dimensional Measurement Interface Standard (DMIS)[6] formatted CMM part program will be created along with the appropriate part set-up and probe configuration support documents.

As illustrated in Figure 4, the IPPEX system consists of five major components: a user interface, a product modelling system, a relational database management system, an object-oriented database system, and an expert system environment which involves an inferencing mechanism and multiple knowledge-bases. The user interface provides the user access to IPPEX's functions. The product modeler supplies the product definition information. The expert system environment controls the inspection knowledge bases and the inference mechanism. The databases contain resource data and plan storage

The current IPPEX prototype system runs on an HP/Apollo engineering workstation. The user interface is an icon-based menu-driven module which interfaces the user to the product modeler and the IPPEX planning system. The current product modeling system involves the Parasolid Solid Modeler[7] complimented by CAM-I's Dimension and Tolerance (D&T) Modeler[8]. The connection to the geometric solid model and D&T information is acquired through the modeler's application programmers interface subroutine library. The data in the relational database are programmatically accessed through embedding SQL constructs in the C language. Finally, the current inferencing environment is NASA's C Language Integrated Production System (CLIPS)[9]. CLIPS is a production rule-base system. It is activated by the IPPEX system through C functions to CLIPS. IPPEX's application routines can initiate CLIPS, assert new facts into the CLIPS fact base, retract facts from the fact base, execute a set of rules, and transfer inferenced decisions.

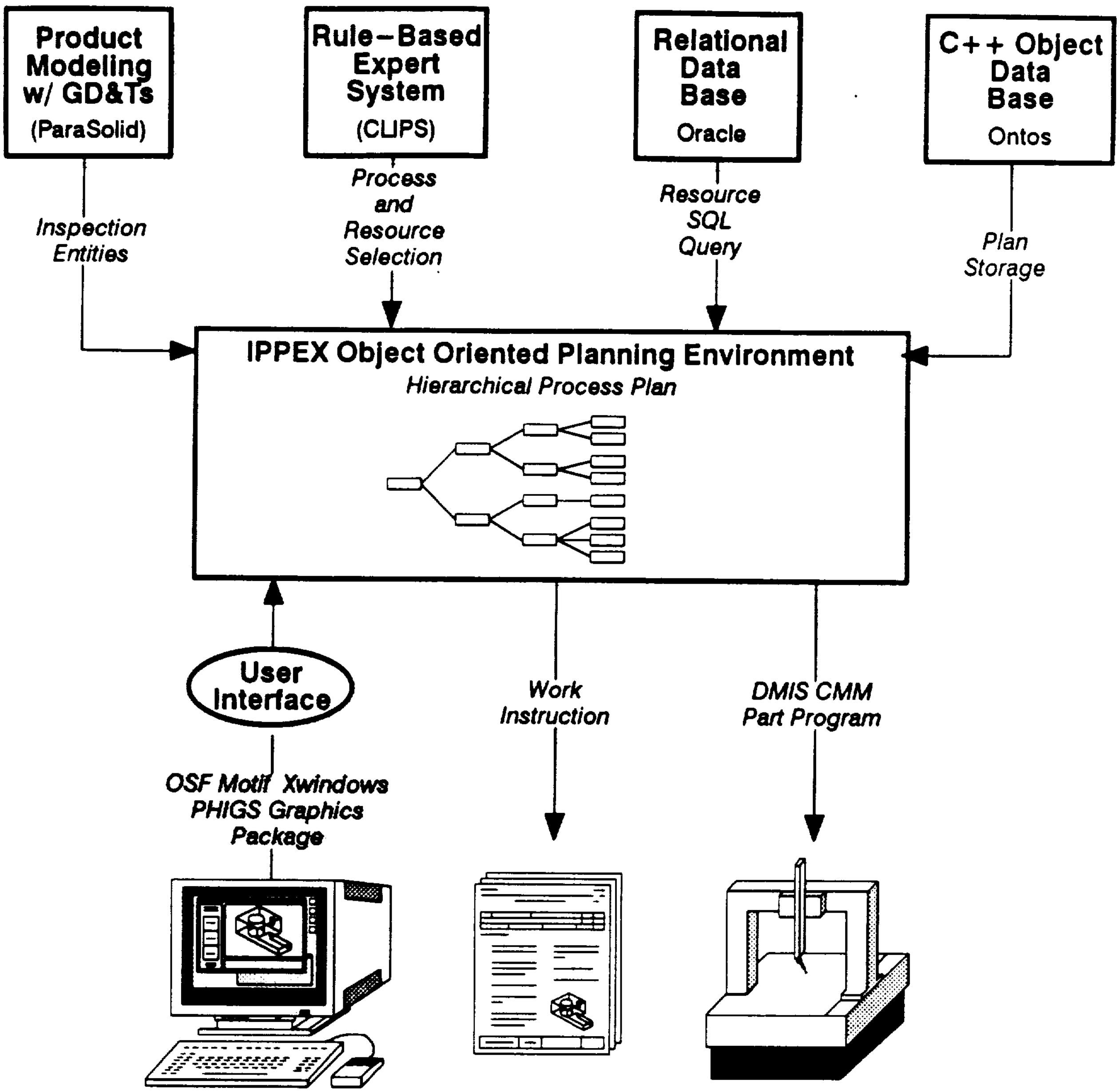

Figure 4. IPPEX System Architecture

Intelligent Scheduling and Planning System

ISAPS[10] is a scheduling and planning tool for shop floor personnel with the responsibility of producing discrete, machined electrical component housings in a Flexible Manufacturing System (FMS) environment. The ISAP system (see Figure 5) has two integrated components: the Predictive Scheduler (PS) and the Reactive Scheduler (RS). These components work cooperatively to satisfy the four goals of the ISAP system, which are: 1) meet production due dates, 2) maximize machining center utilization, 3) minimize cutting tool migration, and 4) minimize product flow time.

The PS is used to establish schedules for new production requirements on a variable planning horizon. It provides finite capacity scheduling for six machining centers, two coordinate measuring machines (CMMs), one automatic wash station, and five manual stations for tooling, part, and fixture preparation. The RS is used to adjust the schedules produced by the PS for unforeseen events that occur during production operations, such as equipment failures, changing priorities, and product mix.

A common model of the FMS is employed by the PS and RS which defines the basic system configuration and availability of resources to be considered for scheduling. The PS and RS subsystem prototypes have been developed using KEE[11], an expert system shell from IntelliCorp, and Common Lisp. The schedules developed by the ISAP system have been validated using a discrete event simulation model of the FMS. The prototypes are currently being converted to the object-oriented C environment, ProKappa[12], also from IntelliCorp.

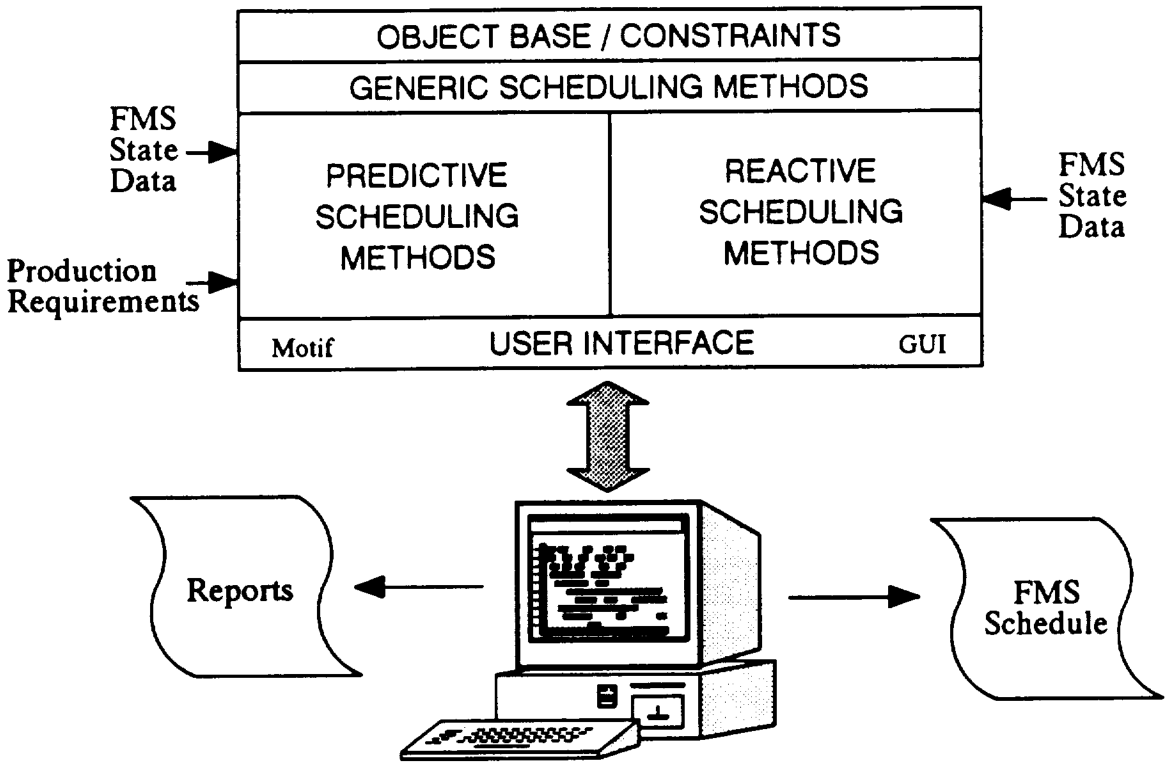

Figure 5. ISAPS System Architecture

IFMP SYSTEM INTEGRATION

The IFMP is in the process of integrating all of the previously described systems into one seamless manufacturing environment. Figure 6 illustrates the flow of information that is required to rapidly produce products targeted for the Flexible Manufacturing System at KCD.

Product definitions will be obtained in electronic form from an outside client in STEP ASCII standard format. The AMDS system will automatically translate this information into product definitions to feed XCUT, IPPEX and ANC. XCUT will use the definition to generate the process plans for the machining operations. IPPEX generates similar plans for the inspection process. These plans are joined together to produce the production plan for the product. ANC takes the production plan, along with the product definition from AMDS, and generates the required N/C programs to machine the product. The second pass of IPPEX generates the DMIS part inspection program. The N/C and DMIS programs are post-processed to their respective native machine codes and electronically shipped to the FMS. ISAPS uses the information embedded in these programs and master production schedule requirements to determine the appropriate schedule to manufacture the product.

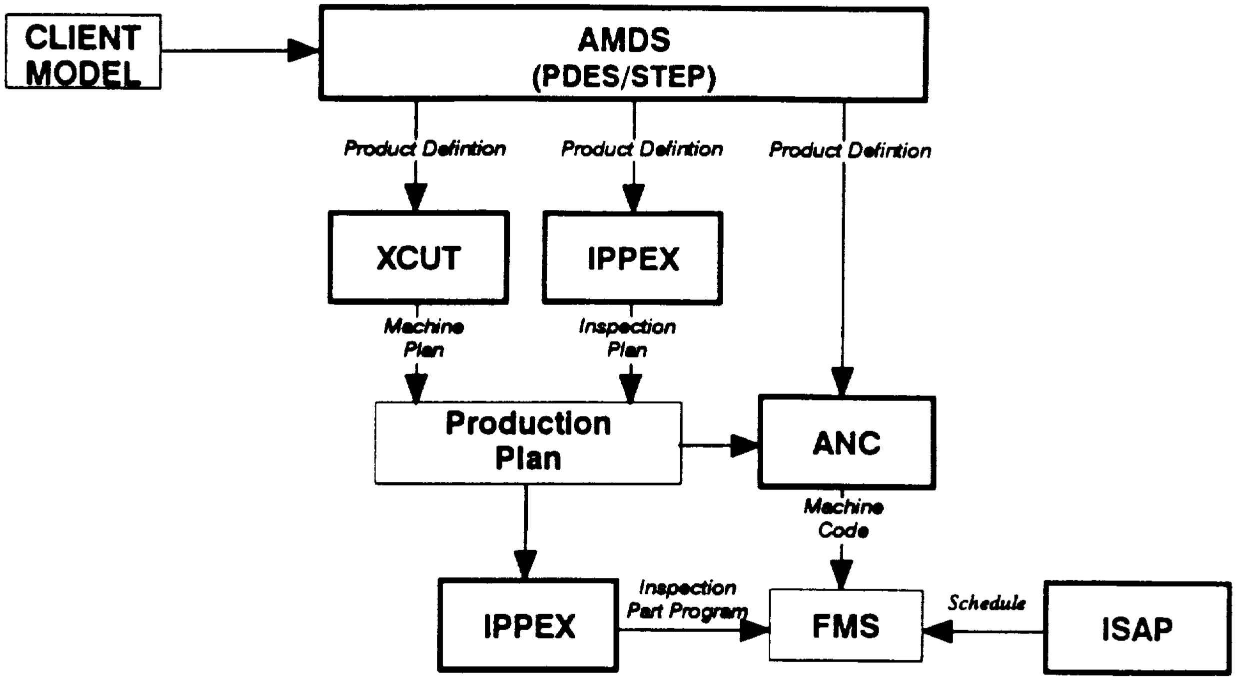

Figure 6. IFMP Information Flow

REFERENCES

[1] Hummel, K.E., Brooks, S.L., and Wolf, M.L., "XCUT: An Expert System for Generative Process Planning," *International Industrial Engineering Conference*, Toronto, Ontario, May 12–18, 1989.

[2] Wolf, M.L., "AIS in Automated Process Planning", *CAM–I* May 17–18, 1988.

[3] Preiss, K., *21st Century Manufacturing Enterprise Strategy*, Iacocca Institute, Lehigh University, Vol. 2 pg. 27, November 1991.

[4] Brown, C.W., "IPPEX: An Automated Planning System for Dimensional Inspection", *Proceedings of the 22nd CIRP International Seminar on Manufacturing Systems: Computer Aided Process Planning*, Vol., 20 No. 2, 1991.

[5] Brown, C.W., "Dimensional Inspection Techniques for Sample-Point Measurement Technology", *Precision Engineering Journal*, American Society for Precision Engineering, Vol. 14, No. 2, April 1992, pp. 110-112.

[6] ANSI/CAM–I 101–1990 "Dimensional Measuring Interface Specification", *Computer Aided Manufacturing – International*, Arlington, TX., 1990.

[7] "Parasolid v3.0 Reference Manual", June 1990., Shape Data Ltd.

[8] Ranyak, P. S.; Fridshal R. "Features for Tolerancing a Solid Model", *Proceedings of 1988 ASME International Computers in Engineering Conference and Exhibition at San Francisco, CA.*, July, 1988, pp. 275–280.

[9] Culbert, C. J. "CLIPS Reference Manual", *National Aeronautics and Space Administration*, Version 4.0, March 1987.

[10] King, M.S., et al, "ISAPS – Intelligent Scheduling And Planning System", *Proceedings of the Design Productivity International Conference*, Honolulu, Hawaii, Vol. 2, Feb. 6–9, 1991, pp. 661–666.

[11] "KEE Software Development System Core Reference Manual", Version 3.1, IntelliCorp, Inc. Mountain View, CA, July, 1990.

[12] "PROKAPPA Programmer's Reference Manual", Version 2.0, IntelliCorp, Inc. Mountain View, CA, October, 1991.

ALLIED SIGNAL, INC.
TECHNICAL CONTACTS FOR IFMP PROJECTS

- **AMDS:**
  John Zimmerman
  Staff Engineer
  (816) 997-2932

- **XCUT:**
  Steve Brooks
  Staff Engineer
  (816) 997-4329

- **IPPEX:**
  Curtis Brown
  Staff Engineer
  (816) 997-3548

- **ANC:**
  Bill Simons
  Staff Numerical Control Analyst
  (816) 997-4739

- **FMS / ISAPS:**
  Mike King
  Staff Engineer
  (816) 997-5175

- **TECHNOLOGY TRANSFER:**
  Dennis Stittsworth
  Manager Technology Transfer
  (816) 997-4596

AN EXPERT SYSTEM FOR SUPERPLASTIC FORMING IN CONCURRENT ENGINEERING ENVIRONMENTS

This paper was withdrawn from presentation