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W. R. Simons Jr.
S. L. Brooks
W. J. Kirk III
C. W. Brown

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INTEGRATED PRODUCT DEFINITION REPRESENTATION FOR AGILE NUMERICAL CONTROL APPLICATIONS

W.R. Simons, Jr., S. L. Brooks, W. J. Kirk III, and C. W. Brown

AlliedSignal Inc.
Kansas City Division*
Kansas City, MO 64141

ABSTRACT

Realization of agile manufacturing capabilities for a virtual enterprise requires the integration of technology, management, and work force into a coordinated, interdependent system. [1] This paper is focused on technology enabling tools for agile manufacturing within a virtual enterprise specifically relating to Numerical Control (N/C) manufacturing activities and product definition requirements for these activities.

1 MANUFACTURING PLANNING FOR AGILE MANUFACTURING

We envision an integrated system that will facilitate designing and manufacturing a product within a given schedule, and at minimal production cost. Simply put, the system will facilitate concurrent engineering practices within the virtual enterprise. They will be open, modular, and extensible so that new products and processes can easily be supported. The tools will run on low cost hardware so that the virtual enterprise is not limited to large and medium size corporations.

1.1 Manufacturing Planning and Control Architecture

Figure 1 represents an architecture for providing the manufacturing planning capabilities that support concurrent engineering within a virtual enterprise.[2]

This architecture developed within the TEAM initiative [2] incorporates a common macro planner, micro planner architecture that is linked to a shop floor controller. The macro process planning system will interpret design features relative to manufacturing requirements and will examine the enterprise resources to support the timely development of globally optimized manufacturing plans. Macro planners will perform process planning up to the point of identifying work cells that will satisfy production requirements. This corresponds to all process planning activities prior to and including the work cell level of the process plan activity tree (see Figure 2). Micro planners will support all process planning activities at and below the work-cell level of the process plan activity tree. This includes fixture selection, tool selection, operation step sequencing, process setup sheet generation, work instruction sheet generation, part programming, and other detailed task level process planning capabilities.

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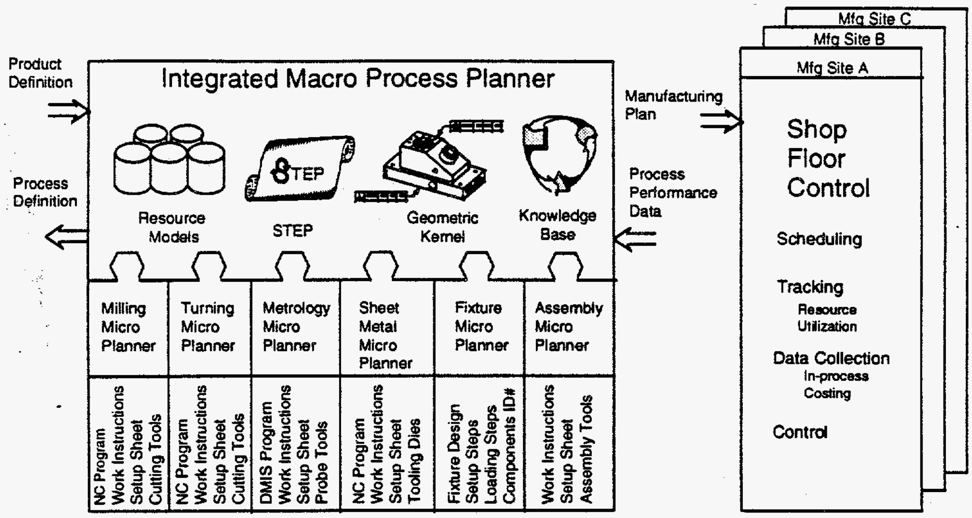

Figure 1: MPC Architecture.

A plug and play integration strategy will provide an extendible architecture so that micro planners can be added to support new processes within the manufacturing enterprise. Details about this architecture are found in the TEAM Strategic Plan - Book 2. There are a number of technological voids that stand in the way of achieving this vision. One of these is the ability to represent complete and unambiguous product definition within a virtual enterprise.

1.2 Complete and Unambiguous Product Definition

Traditionally, product definition is thought of as merely the shape or geometrical description of a piece part. It is in fact, much more than this. A complete and unambiguous product definition representation is the key integrating force underlying the manufacturing planning systems. Form features provide alternative viewpoints of product definition and are integral to agile N/C part programming capabilities. This paper describes the integrated product definition components that will support N/C capabilities within the agile manufacturing virtual enterprise.

2 BACKGROUND

The foundation for our current development activities stems from four advanced manufacturing development efforts at AlliedSignal Kansas City Division (ASKCD) including: a knowledge based generative process planning system called XCUT (Expert Cut Planner); [8] a knowledge based generative automatic N/C part programming system (ANC Advanced Numerical Control); a generative process planning and part programming system for Coordinate Measuring Machines (IPPEX: Inspection Process Planning Expert); and a STEP based product definition translation system (AMDS: Advanced Manufacturing Development System). Each of these efforts was focused on a specific application within the manufacturing enterprise. The common bond between the systems is product definition representation. Therefore, when the projects came together in 1992 to form the IRIM (Integrated Rapid Intelligent Manufacturing) project, the priority task was to arrive at a common product definition strategy.

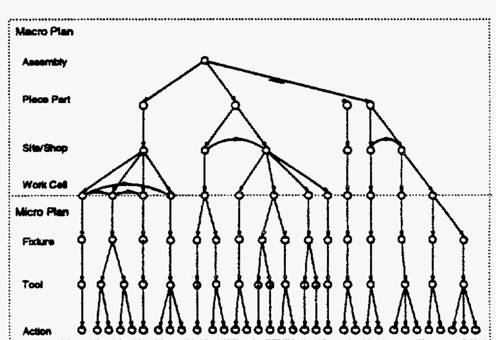

Figure 2: MPC Process Plan Activity Tree

Current activities at ASKCD include development of a milling/drilling micro planner that incorporates the manufacturing planning and control architecture shown in Figure 1. The milling/drilling micro planner will utilize solids model based form features for product definition representation. Previous process planning and part programming prototypes (mentioned above) were focused on automation capabilities. While the micro planners will ultimately incorporate knowledge based automation capabilities, the initial focus will be to provide flexible computer aided capabilities. Micro planners are being developed on the Windows NT operating system and low cost PC based hardware. Object oriented techniques are being utilized for analysis and design of the system. The Visual C++ programming language, ACIS ® geometric modeler, Strata™ Development Environment, and ACIS ® 3D Toolkit [9] are being utilized for implementation of an initial prototype. *(Note: ACIS is a registered trademark of Spatial Technology Inc.)*

3 NUMERICAL CONTROL INFORMATION REQUIREMENTS

While product and process definition represent the key information required for process planning and part program generation, there are other information requirements that are essential.

3.1 Process Definition

We have adopted the ISO 10303 (STEP) product data definition, which espouses the idea that product defining information includes product data throughout the life cycle of a product. Therefore, product data includes process definition which is the definition of all process information utilized for realization of a product.

Because of our desire to provide process planning and part program creation capabilities for a wide variety of parts, we have identified a generative rather than variational approach for process plan and part program creation. A generative process planning/part programming system is based on geometric reasoning, and process/resource models. Generative part program creation within a micro planner is based on the existence of a sequenced process plan. Automation is performed by sequentially stepping through the process plan and processing information using knowledge based techniques.

3.2 Manufacturing Resource Information

Each micro plan level within the process plan activity tree (Figure 2) points to information required for process plan and part program generation. The work-cell level will provide information relating to the specific machine tool being used as well as characteristics of the work cell. Maximum work piece (the initial rough stock) size, horse power ratings, tooling, and travel limits are examples of key information required for process plan and part program generation.

The fixture level within the activity tree points to setup information including information relating to the work holding devices. Setup information includes orientation of the work holding device(s) on the machine tool, orientation of the work piece(s) on the work holding device(s) and requires a complete and unambiguous solid model based product definition representation. Work holding information will effect decisions relating to process selection, tool selection, tool motion control, and other key factors relating to process plan and part program generation.

The tool level of the activity tree points to tooling information which for milling and drilling, is not limited to just cutting tools, but includes all tools used within the process of product realization. For N/C part program generation purposes the majority of tooling information requirements will be found in the cutting tool and cutting tool holder classification.

While the main scope of this is paper is on milling/drilling micro planning, We would be remiss to exclude the point that machine tool, fixturing, and tooling information is especially important at the macro plan generation level as well. Determination of enterprise capabilities and scheduling constraints could not be performed without an accurate, complete and unambiguous machine tool, fixturing, and tooling product definition representation. This information is vital for establishing an agile manufacturing capability within a virtual enterprise.

Other information requirements for process plan and part program generation include knowledge representation, machinability information, coolant information (sometimes classified as a tooling resource), scheduling information, and personnel/enterprise information. This is mentioned simply to ascertain the complexity of the problem. A complete and unambiguous product definition representation is essential in realizing a truly agile manufacturing capability. In light of this, the point that must be made is the criticality of information standards and the importance of current STEP activities which are focused on product definition information standards.

4 PRODUCT DEFINITION

"Integration of the data that defines the shape of a product with the data concerning its configuration and make up is essential to an organization's ability to define its products" [3] and is of particular importance in process planning and N/C part programming applications. Product Definition representation within the milling/drilling micro planner is based on BREP (Boundary Representation) solid model based form features.

4.1 Form Features

"The definition of a feature is very simply a classification of object characteristics which have significance in some domain." Although this is an admittedly vague definition for features, it accurately represents the idea that a feature only exists because it is significant for a particular type of task or reasoning activity. [4] Based on this definition we must be careful to acknowledge that the definition of a feature from the perspective of the design task in many cases will be much different from the perspective of a manufacturing task. Figure 3 provides a good illustration of how the perspective of the feature creator affects the definition of the feature. Notice that there are four manufacturing features (M1 - M4) that are defined in order to produce the boss on the top of the part. On the other hand, it is likely that the designer would only create one protrusion feature to represent the boss. Also notice that the shape of the manufacturing features are dependent on the work-piece shape which is not known at the initial design stage.

Ruling out the idea that designers must use manufacturing features to design, multiple feature perspectives must be provided to support various application domains. Since product definition input to manufacturing comes in the form of design features, we must provide a way to map features from the design perspective to the manufacturing perspective. In other words, we must provide the capability to map design features to manufacturing features, and vice versa.

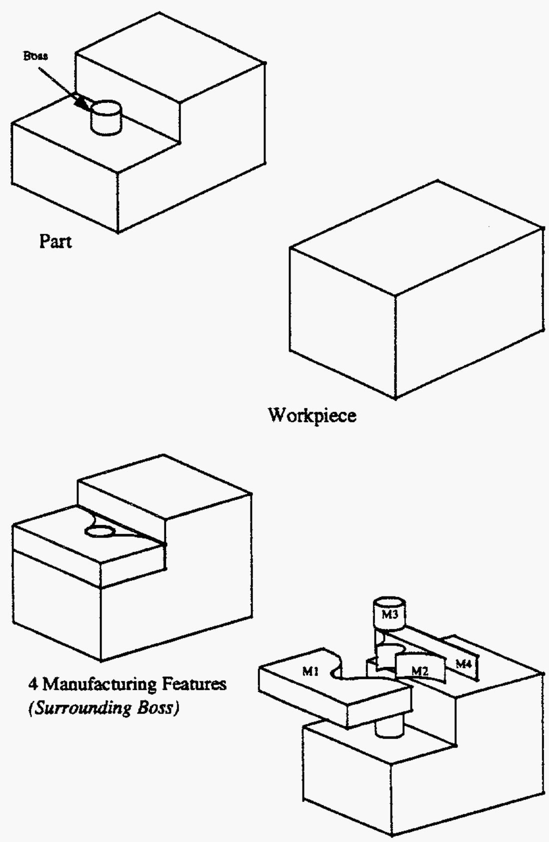

Figure 3: Boss Design Feature => four Manufacturing Features

Although it is possible to have a one to one mapping between some design features and some manufacturing features, we believe that this is the exception rather than the rule. This is especially apparent with protrusion type design features as illustrated in Figure 3. The design feature (boss) may map to one or many manufacturing features (M1-M4).

The common denominator between design features, manufacturing features, and other feature definitions (i.e. tolerance features) is the underlying BREP topology. Assuming that it is possible to assign persistent design feature identifiers to BREP entities (i.e. face, edge, vertex) and that these identifiers can be translated to the final BREP representation of the part/product, the approach that we have adopted for feature mapping is to simply utilize the underlying BREP topology as a point of reference for multiple feature definitions. The milling/drilling micro planner incorporates two form feature definitions, manufacturing features, and tolerance features.

4.2 Milling/Drilling Manufacturing Features

The manufacturing features that will be utilized by the milling/drilling micro planner will provide full flexibility to the user. Flexibility demands providing tools that will allow the user to define any type of material removal volume shape. At the same time, the feature concepts will also lay the ground work for automatic change propagation (or associativity) within the system. This associativity will be based on design and process modifications.

The manufacturing feature model is divided into two separate modules, shape aspect, and representation. The shape aspect module provides the conceptual shape definition of the feature. The representation module defines the geometric representation of the feature [6]. We will utilize a process walk-through to explain what some of these conceptual features are and how they will be utilized in the system.

4.3 Manufacturing Feature Walk Through

The user will begin by importing the part definition into the system in the form of a BREP solid model. A work piece (representing the rough stock) will then be imported or created. The user will then import the work holding device and re-orient the part to the fixture, and the fixture to the machine tool.

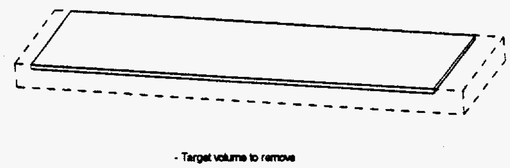

Figure 4: Removing A Rectangular Slab

The example that we will use to illustrate our feature concepts involves a single tool face milling operation that is performed on a slab manufacturing feature (Figure 4). The ultimate goal is to provide a feature recognition capability that will automatically recognize and classify manufacturing features. Before this is accomplished, it is important that a manual capability be perfected first. Therefore, the user will begin by creating a "clipping space" that defines the feature's extent for the material removal operation. It is important that all manufacturing features relate to the original part. This will facilitate associativity between the part and the manufacturing features. Therefore, construction of a clipping space begins by first constructing faces that are offset from the part. (Figure 5)

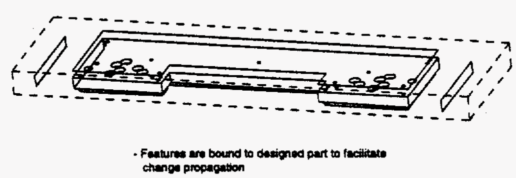

Figure 5: Offset Faces

The clipping space which represents the extent of the slab feature is an unbounded space that is represented by a Boolean intersection of 3 half spaces (Figure 6). Other types of clipping space representations will be available (i.e. sweeps) to provide flexibility in defining material removal extents.

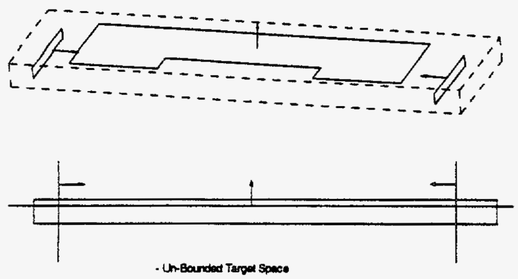

Figure 6: Clipping Space

The user defines feature extents for all material removal tasks. Once these clipping spaces are defined, the system will evaluate the clipping spaces and automatically generate the "Feature Removals."

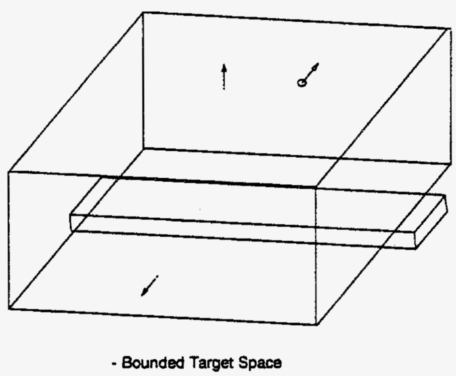

Figure 7: Feature Removal

The Feature Removal defines the bounded target space and is represented by a solid model. The user will then create the process plans and order the Feature Removals. Once the feature removals are ordered, the user will initiate an evaluation process which generates Delta Volumes, and Interaction Volumes (explained later).

To generate Delta Volumes, the solid model representing the Feature Removal is intersected with the "As-Is" state (feature representing the current shape of the part) which initially is the equivalent of the "Initial State" or initial work piece (see Figure 8). A Delta Volume represents the material volume to be removed from the work piece in order to produce the part. Feature Removals are also utilized to produce Interaction Volumes.

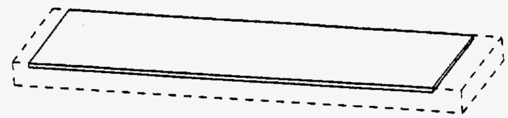

Figure 8: Delta Volume

Interaction Volumes represent manufacturing feature interactions. Figure 9 illustrates an interaction volume (INT1) that represents the interaction of two feature removals (FR1, FR2). These two feature removals represent the bounded target space relating to the removal of two slots. Interaction volumes are utilized for process ordering activities, and for creation of NC Removal Features.

A NC Removal Feature specifies the volume of material that will be targeted for a single N/C removal operation. An N/C Removal operation references a single toolpath and relates to one or many delta volumes and zero, one, or many interaction volumes. For instance, if FR1 was machined prior to FR2, the actual solid model used as input for the toolpath creation algorithm would be the union of the delta volume generated by FR2 (a 2 lump solid) and INT1. NC Removal Features include feature element information (i.e. top, bottom, side) and are classified (i.e. pocket, step, slot) to facilitate knowledge based automation capabilities.

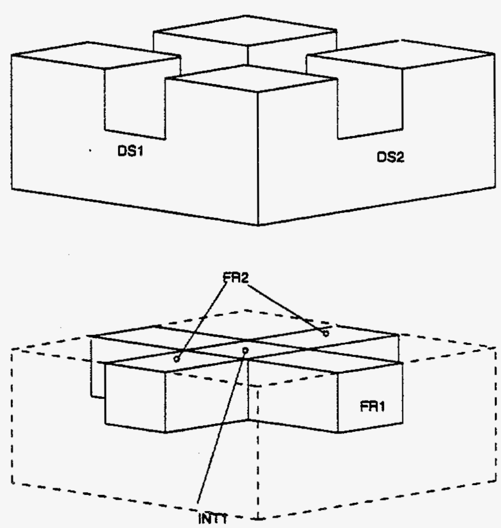

Figure 9: Interaction Volume

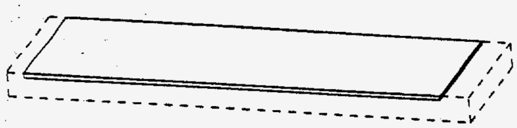

Figure 10: NC Removal Feature

"In-Process States" which play the role of initial states, as-is states, or to-be states, provide an accurate representation of the part shape between operations. They are generated by subtracting the delta volume from the current "as-is" state. So, the delta volume in Figure 10 would be subtracted from the current "as-is" state (which is also the initial state since this is the first material removal operation) to produce the In-Process state in figure 11.

Figure 11: In-Process State

The manufacturing feature model also includes a feature called "Material Removal Feature" which is a collection of BREP topological entities (i.e. face, edge) in the finished product that will appear when the material is removed. Since this feature includes references to the part, it serves as the main factor in providing change propagation capabilities.

The milling/drilling micro planner will also utilize Tool Volumes. Tool Volumes are defined as features that represent the volume of space that a toolpath moves through while cutting the part. These features will be used for software quality assurance capabilities including collision detection, and toolpath verification.

4.4 Tolerance Features

Another key element of product definition that is vital to process planning and part program generation is tolerance information and general property attributes. Manufacturing features will be integrated with tolerance features. These tolerance features provide full support for ANSI Y14.5M-1982 and will provide capabilities that will guarantee a complete and unambiguous definition for tolerances. The milling/drilling micro planner will include a tolerance feature creation capability. This is necessary for creation and modification of in-process tolerances. Since Manufacturing Features are integrated with tolerance features through the BREP topology, access to tolerance information is not a problem. Also, change propagation based on tolerance feature modifications will be possible. (Refer to [5],[7] for details.)

4.5 Change Propagation

Automatic change propagation is an important feature within the micro planning system. The integration of manufacturing feature entities to the BREP topological entities provides a path for change propagation which is triggered by modifications to the part design or modification to tolerance features. Change propagation based on design modifications will initially be limited to automatic NC Removal Feature regeneration, and identification of NC toolpaths that are affected by the change. When knowledge based automation capabilities are added, it will be possible to automatically modify toolpath parameters and regenerate the toolpath.

Since manufacturing features point directly to process plan entities, modifications to process planning information will also trigger change propagation. Until knowledge based automation capabilities are added, propagation of change to process planning information will be limited to identification of affected manufacturing feature, process planning, and part programming entities. There are instances where modifications within the system will not propagate change (e.g. addition or deletion of topological entities). In these cases the system will identify those manufacturing feature, process plan, N/C part program, and tolerance feature entities that are affected by the change. At this point, user interaction is required for propagation of changes. [6]

5 SUMMARY

A complete and unambiguous product definition representation is the key factor in realization of agile manufacturing capabilities. Multiple manufacturing feature concepts are used to accommodate flexibility, and provide automatic change propagation throughout the milling/drilling micro planning system. Tolerance features provide dimension and tolerance information (i.e. surface finish, positional tolerance, size tolerance) and are integrated to support manufacturing needs. An object oriented design methodology is being utilized for analysis, design, and implementation of all manufacturing feature, tolerance feature, process plan, part programming and other modules incorporated in the system. Development of information standards specifically for product definition (STEP) is critical for realization of agile manufacturing capabilities.

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7 BIOGRAPHICAL SKETCH

WILLIAM R. SIMONS, JR. is a Staff Numerical Control Analyst at AlliedSignal Aerospace Co. with a BS in Industry and Technology from Northern Illinois University. His areas of specialization include: software engineering, solid modeling applications, numerical control programming, and application development.

STEVE BROOKS is a Staff Engineer at AlliedSignal Aerospace Co. and a Ph.D. Candidate at the University of Kansas. His areas of specialization include: software engineering, solid modeling applications, process planning and graphics programming.

WHITSON J. KIRK III is a Senior Engineer at AlliedSignal Aerospace Co. with a MS EE degree from University of Missouri, Columbia. His areas of specialization include: software engineering, neural networks, solid modeling application, object-oriented programming and graphics programming.

CURTIS BROWN is a Staff Engineer at AlliedSignal Aerospace Co. with a MS ME from the University of Kansas. His areas of specialization include: software engineering, solid modeling applications, coordinate metrology process planning, and dimensioning and tolerancing.