

TEAM

Technologies Enabling Agile Manufacturing

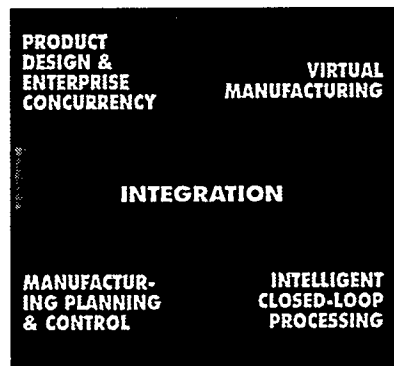
Macro Planner Requirements Guide

VERSION 1.0
28 March 1995

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Table of Contents

TEAM MACRO PLANNER REQUIREMENTS GUIDE.....	2
1. PERFORM MANUFACTURING ANALYSIS.....	5
1.1 Identify Category of Planning.....	5
1.2 Evaluate Product Definition Completeness.....	5
1.3 Retrieval of Historical Manufacturing Plans.....	6
1.4 Identify Best Similar Product.....	6
2. PART/PROCESS UNDERSTANDING.....	8
2.1 Identify Features & Tolerances.....	8
2.1.1 Nominal Features Recognition.....	8
2.1.2. Raw Material Selection.....	9
2.1.3. Tolerance Analysis.....	9
2.1.4. Detailed Feature Creation/Association.....	10
2.2 Manufacturing Plan Optimization.....	10
3. PROCESS SELECTION AND ORDERING (AS-IS/TO-BE DESIGNS).....	12
3.1 Develop Resource Base.....	12
3.1.1 In-Process Feature Selection.....	13
3.1.2 Feature And Process Mapping.....	13
3.1.3 Candidates Pruning.....	13
3.1.4 Machine Tool Selection.....	13
3.1.5 Machine Tool Representation.....	14
3.1.6 Potential Machine Candidates For Each Operation.....	14
3.1.7 Preferred Machines Associated With Each Operation.....	14
3.1.8 Set-Up Planning.....	14
3.2 Generate Routing.....	14
3.2.1 Associate Resource Group to Route-Operation.....	15
3.3 Generate Bill Of Material.....	16
4. PLAN/PERFORMANCE ANALYSIS.....	18
4.1 Create Manufacturing Plan Evaluation Criteria.....	18
4.2 Evaluate Manufacturing Plan Performance.....	18
4.3 Identify Alternatives.....	18
4.4 Assign Grade.....	19
4.5. Establish Manufacturing Plan Business Methods.....	19
4.5.1 Evaluate Requirements For Mfg Plan Business Method.....	20
4.5.2 Identify Affected Mfg Plan Business Method.....	20
4.5.3 Generate Mfg Plan Business Method.....	20
4.5.4 Generate Operation.....	21
4.5.5 Evaluate Use Of Mfg Plan Business Method.....	22
5. PROCESS DOCUMENTATION AND CONFIGURATION CONTROL.....	23
5.1 Evaluate Comments.....	23
5.2 Determine Affected Manufacturing Plans.....	23
5.3 Archive Manufacturing Plan.....	24
Appendix A. Glossary of Terms.....	25
Appendix B. Publications.....	27
Appendix C. Business Cycle Flows.....	28
Appendix D. Macro Planner Participants.....	30

TEAM Macro Planner Requirements Guide

Manufacturing is undergoing rapid change with demands for rapid response and the application of cost effective processes. In order to be responsive to these competitive demands, traditional manufacturing planning methods must also change. This has already occurred or is now happening in many manufacturing operations. The driver for this change is the need for shorter lead-times, i.e. the time between placing an order and delivery of the manufactured product at lowest cost. To do this, manufacturing planning must now accommodate and support concurrent product/process design for manufacture/assembly. Manufacturing Planning will not exist in a world unto itself. The planning process must tear down the walls between design, planning and the shop floor. The team will draw on the strengths of all participants to shorten the planning process and to make critical information available on all activities for optimizing performance.

Figure 1 shows the high level view of the interactions between the Macro Planner and the other activities in the enterprise. The interactions shown in this diagram are intended to be iterative in nature and specific exchanges between modules will depend on which of the three business cycles are active at any specific time (See Appendix C).

At the earliest conceptual design phases, the product design and macro planner interactions will deal with potential manufacturing problems and candidate processes that could be used for manufacturing the part. It is anticipated that the part design team (including planners) will utilize the information about product features, tolerances and performance concerns to communicate with the customer to optimize the product design.

At the detailed design phase, the basic features and tolerances of the part have been determined and the Macro Planner and Micro Planner will cooperate to optimize and validate/extend definition of the process selections and validate cost and quality estimates. The basic state of the part at the input and output stage for each operation will be determined. Fixturing, tooling and cutting tool elements will also be determined. This interactive design of product and processes is commonly termed concurrent engineering. The manufacturing enterprise of interest may be geographically distributed and may encompass elements of several companies joined for a particular product manufacturing endeavor.

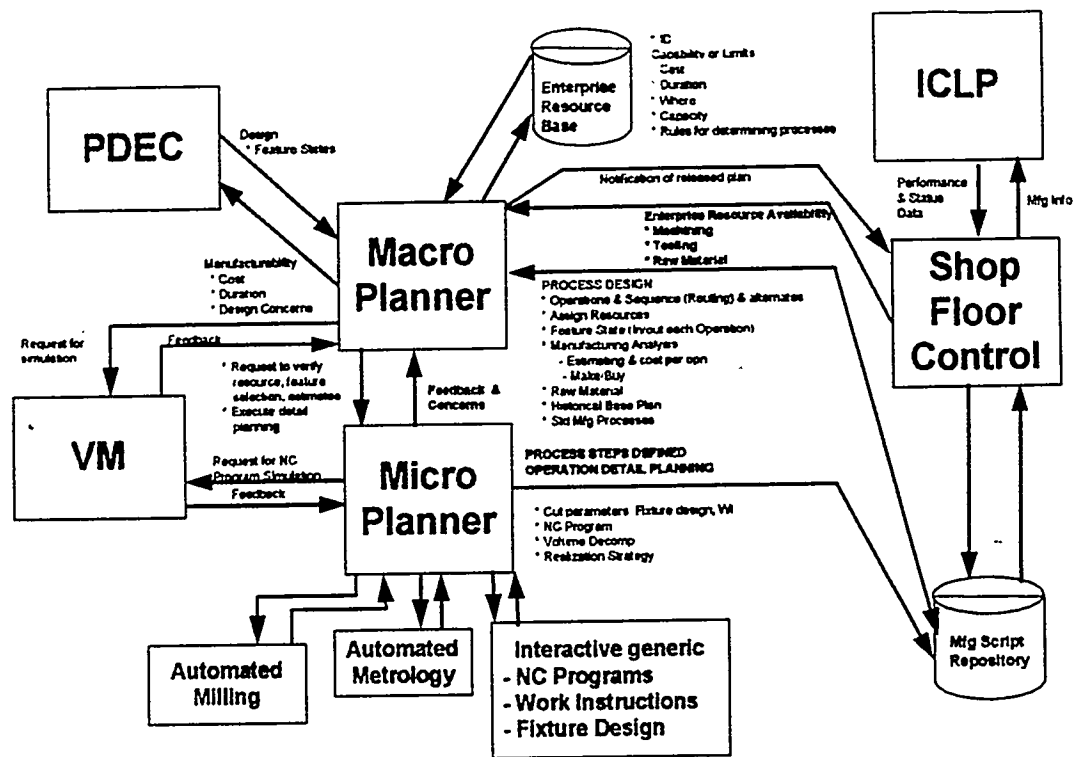
At the detailed engineering phase, after an order has been received, the Micro Planner will produce the detailed fixture and tooling designs, NC part programs, work instructions, setup plans and documentation. The Micro Planner will request analytical validation and verification of its deliverables in concert with Virtual Manufacturing activities. The Macro Planner will interact with the Micro Planner to compile the identities and description of the information into a configuration controlled master Plan.

The Macro Planner will provide required resource identities, bill of material list, routing sequences and identities of all supporting information to the Shop Floor Control System to enable the actual manufacturing activities. The Macro Planner must also collect manufacturing performance data from the shop floor to effectively measure the plan's performance. The critical feedback will be evaluated during closure of the business cycle and provide the metrics on cost and quality to the planning function.

This document is intended to describe the requirements for a Macro Planner system which supports the above environment. The Macro planner should progress to a logically, rule driven processor to automate major portions of the planning cycle. It should do the following:

- * Support concurrent product/process design
- * Define a globally optimized manufacturing plan for realization of product
- * Compile a complete manufacturing plan script (routing and operational detail documentation)
- * Be based On 3-D CAD models imported via STEP standards
- * Define an Enterprise Resource Base that maps manufacturing capabilities to component features.

This document is based on initially implementing a variant process planning system, but evolving to a feature based system which is capable of intelligently selecting globally optimized process steps and supporting other modules generating detailed planning information. A variant process planning system traditionally uses group technology classification schemes to retrieve plans for similar products and creates a new plan by modifying the best similar existing plan. The next technological step in manufacturing planning is to migrate to a generative (knowledge-based) planning system through the development of standard methods, computer intelligent product models, and incorporation of captured process knowledge. A generative system may use group technology or other organizational means to classify a product/part family and then automatically create a specific part manufacturing plan using the accumulated knowledge-base to build the plan. The generative planning system will utilize features as the basic building block and a resource base to identify relevant processes. The manufacturing engineering tool set will incorporate the capability to simulate manufacturing operations for validation or to identify needed modification to the generated plan to correct or provide additional detail.



MPC Interactions

Figure 1

Knowledge-based Interactive Process Planning

One suggested strategy to hasten the achievement of the long term automated generative planning system goal is to expand and improve on the traditional Variant Process Planning approach by quickly transitioning to a Knowledge-Based Interactive System Environment. The Interactive System Environment must provide end-user capabilities for quickly leveraging technology developments furthering the implementation of generative components offering cost-effective solutions to problems of macro and micro process planning. Within the Manufacturing Planning and Control thrust area of the T.E.A.M. program, elements of the Macro Planner and specific micro planners will illustrate knowledge driven systems. The basic architecture of the Macro and Micro planners will also accommodate introduction of information from traditional tools through interactive sessions for inclusion.

The Macro Planner will support Manufacturing Design Planning, a joint effort between designers and planners to provide functional designs which meet customer needs but are sensitive to realities of manufacturability for product. The system references the manufacturing and quality process knowledge of the product center and provides on-going guidance to the product designer of manufacturing best practices, processes available and control limits. The goal is to achieve a ready capability to quickly provide advance advice that can be reflected in the design, based on analysis of the manufacturability of the part design including costs and identify suitable areas for possible design changes, which would improve manufacturing cost and performance.

Manufacturing Shop Planning integrates the manufacturing and quality planning processes into a combined set of detailed operational plans which are used to control the execution of all manufacturing and testing operations for orders actually placed in the product center.

The Macro Planner will support processes to determine Manufacturing Plan performance. The process will provide monitoring and comparison of as built product information to the plan in order to continually update, modify, and improve the total manufacturing plan as well as the manufacturing planning process. Improvements in the manufacturing planning process are obtained through the creation of manufacturing plan business methods (standards) which are then incorporated into existing and future plans. As the system evolves to a rule driven generative process, mechanisms to maintain a log about concerns/violations or the introduction of additional criteria for existing body of captured knowledge must be provided.

Figure 2 illustrates the process planning interactions shown in Figure 1 and expands the Macro Planner and Micro Planner into functional modules. The following sections of this requirements document will describe the activities and information exchanges that are resulting during the Macro planning process.

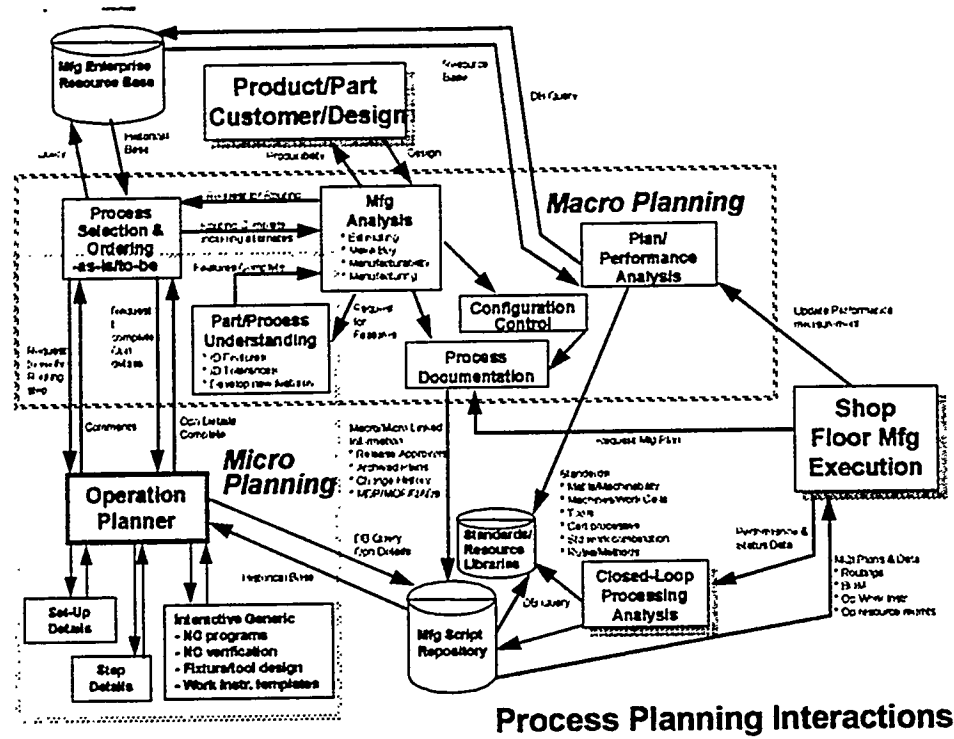


Figure 2

1. PERFORM MANUFACTURING ANALYSIS

This process initiates the activities required to begin the manufacturing planning function. This includes both evaluating requirements necessary to initiate manufacturing planning and performing manufacturing analysis and assessments. Evaluating the requirements includes identifying the category of planning, evaluating electronic product definition information for completeness and manufacturing feasibility, providing comments on the product definition information, identifying the group technology scheme for a product, identifying the best similar product from the manufacturing planning historical database, and establishing manufacturing criteria.

It is expected that these activities may be executed in joint effort with the design team via the enhanced computer networking technique. The initial activities may be interactive but are expected to migrate to a logically driven process based on a data object repository which captures critical information on part features, process identities and capabilities across the distributed enterprise.

1.1 Identify Category of Planning

This process identifies and records the category of planning associated with a manufacturing plan. The selected category of planning dictates the work flows of the manufacturing planning process. The categories of planning are dependent on the planning phase, complexity of customer product requirements, schedule, etc. The assignment of a category is accomplished by evaluating each order and the associated product definition against the standardized planning category criteria and selecting the applicable category. The planning category of a product may change over time, but only one category of planning will exist per version of a manufacturing plan.

Requirements

The system shall:

1.1.a - For a manufacturing plan for a product, record the planning category.

- | | |
|-------------------------------|--|
| - Conceptual design | - Priority Rush Order |
| - Detailed design (RFQ) | - Long range planning |
| - Detailed engineering phases | - Enterprise modeling scenario studies |

1.1.b - Retrieve manufacturing plans for a specified planning category.

1.1.c - Display menu of planning categories to select from when retrieving by, or updating the planning category.

1.2 Evaluate Product Definition Completeness

This process reviews current available version of product definition information to identify manufacturing features and to examine for completeness needed for the category of manufacturing planning, to determine clarity of requirements, and to identify quality requirements and concerns. Any lack of completeness, understanding, correctness, or quality concerns for a feature or interaction among features are resolved with the design team.

This process is accomplished by evaluating product definition information (evaluation may be iterative occurring several times as features are added to the part) using the evaluation criteria established for each planning category and identifying any non-matches, understanding design intent (form and function), evaluating the design to determine if it will meet the intended use, and interfacing with the Product Definition system to resolve any problems.

Requirements:

The system shall:

1.2.a - Support participation with the design team and transmit evaluation information to and from the product definition and customer management business areas. The capability to edit and highlight proposed changes should be provided.

1.2.b - Acquire the product definition via electronic transfer for a non-ambiguous solids model based design per STEP standards. Interim alternative(s): a) CAD solid model with separate attributes, constraint data tolerances, material specs, etc.) and all necessary identification or b) CAD model with separate attributes constraint data, and/or complete drawings and illustrations

1.2.c - Graphical users interface (GUI) with point and click 'easy-to-use' features. Browse product/part listings and view on demand. Select and acquire product definition sub-sets for more detailed processing assuming varied levels of computer program assist.

1.3 Retrieval of Historical Manufacturing Plans

Group technology (GT) has been used to classify products into families (i.e., material removal, sheet metal formed product and electrical/electronic assemblies) to assist in retrieval of similar products and in developing standard manufacturing business methods for product families. Since individual companies or manufacturing business partners of the agile, distribute enterprise will have their own unique circumstances, the GT scheme employed needs to allow the flexibility in form and depth of GT code.

As intelligent product models and standards are developed and become capable of supporting more direct and automatic identification methods, the Macro Planner must also be capable of transitioning from whatever GT scheme is initially employed to the new methods based on Features or a features list for each product. The shape and form features will be STEP AP224 compatible.

Requirements:

This system shall:

- 1.3.a - Classify product using a database/hierarchical attribute GT classification scheme with at least three tiers and one additional tier for user defined attributes. This system should accept attributes values composed of numeric, alphanumeric, or text strings as applicable.
- 1.3.b - Display definitions of desired attributes and prompt for acceptable values, for a particular GT classification scheme.
- 1.3.c - Accept user defined GT classification schemes.
- 1.3.d - Maintain multiple classification schemes to support piece parts, assemblies, part program, or tooling.
- 1.3.e - Allow partially complete GT classification scheme to the detail level known.
- 1.3.f - Accept multiple CAD based 3-D solid models through a STEP based interface.
- 1.3.g - Provide feature recognition analysis and query user for acceptance of features found.
- 1.3.h - Provide a user interface to identify additional features not automatically recognized.
- 1.3.i - Build a composite manufacturing features list for released product designs.

1.4 Identify Best Similar Product

This process identifies the best similar product from the historical manufacturing planning database using the product identifier, the GT classifying attributes, or the feature list. This includes referencing any associated plans previously established for a product (i.e. RFQ, Long Range Planning). If no plan exists, manufacturing plans will be created with no or very limited historical information.

Requirements:

The system shall:

- 1.4.a - Retrieve products from on-line manufacturing plan repositories by both product identifier, GT classification scheme (full or partial scheme) and features lists. Initially the plan repository may be a physical file or database, but the evolution will be toward object-oriented shared data repositories.

1.4.b - Identify, retrieve and display all manufacturing plans associated with any product that is retrieved by any of the retrieval methods.

1.4.c - Record that no associated or similar products are applicable (i.e. creative planning).

1.4.d - Record person and reason for selecting a product as the best match, and the search criteria and scheme used.

1.4.e - Retrieve products and/or plans from on-line manufacturing plan databases by both drawing number and attributes.

1.4.f - Retrieve products from off-line archived manufacturing plan databases by any of the following: product identifier, GT classification scheme, attributes, and feature list.

1.4.g - Present Manufacturing Plan post evaluation comments to evaluate strengths, weaknesses, and alternatives of plans in determining best similar product.

1.4.h - Segregate and select products based on the availability of information for a similar planning category.

1.4.i - Advise of primary manufacturing domain or processes required for further processing of selected part and acquired definition. Also will advise of secondary domains or processes and other relevant reference information based on the system's current capabilities.

1.4.j - Provide an option for implementing organization to customize naming convention of manufacturing domains in either flat(er) or nested groupings, e.g.

1.4.1. a) Machining, b) Sheet metal, c) Tubes, d) Composites, e) Assembly, f) Overhaul and Repair, g) Chemical, etc. or

1.4.2. a) Fabrication, b) Assembly, c) Testing, d) Overhaul and Repair, etc. Fabrication sub-group could maybe take the form of i) machining, turning, milling, drilling, grinding, etc. ii) sheet metal-forming, joining, etc. iii) tubes, etc.

1.4.k. User option and/or system administration setup to determine and/or restrict domain(s) for further planning focus

2 PART/PROCESS UNDERSTANDING

In general terms the Part/Process Understanding & Process Selection activity of the Macro Planner system maps product definition geometry to product operations and routing. Group technology (GT) will be the initial method used to classify products into families to assist in retrieval of plans for similar products and in developing standard manufacturing business methods for product families. Some companies may classify products to identify major processing steps and the GT codes would need to relate to the composite processing scheme. A product center may choose to re-organize into groups of self-contained work cells, each capable of handling all operations for any one part family. In this case, the product center and each of its work-cells would function as a independent GT code, automatically providing a classification for that part family.

As intelligent product models and standards are developed and become capable of supporting more direct and automatic identification methods, the Macro Planner (under the Knowledge based Interactive Process Planning concept) must also be capable of transitioning from whatever GT scheme is initially employed to the new methods. These new methods are to be based on standard manufacturing features within the product definition models. The manufacturing features employed at the Macro Planner level are the basic work elements (when coupled work tolerances and reference surfaces) which are capable of being linked to appropriate process steps needed to generate the feature. The details of how to generate the in-process features such as material removal sequences are not addressed at this level. The system should use 3-D CAD solid models imported via the STEP standard. The system needs to be feature based and PDES/STEP AP224 standard compatible.

2.1 Identify Features & Tolerances

For a discrete part design, Macro Planner requirements are to understand the shape and non-shape features of the part, provide a capability to analyze the dimension and tolerance specifications, and select the shape/form of the raw stock, and to identify the sets of processes and machines suitable for processing of the set of features for the part. The Macro Planner will create and share access to a knowledge-base, all its functions and capabilities including feature recognition, with a Micro Planner to effectively examine a new product for its features and to identify appropriate candidate processing techniques to realize the feature. The logical rules to associate features and processing steps will be developed and incorporated. The Micro Planner will further decompose the high level manufacturing features to specific task features (material removal) necessary to perform detailed engineering necessary to support manufacturing activity on the shop floor including NC part programs, work instructions, setup instructions, and fixturing and tooling definition.

Feature recognition involves the understanding of the shape and non-shape features of the product definition. These features include, at a minimum, the following:

- Depression features.
- Surface features.
- Edge features.
- Implicit features.

2.1.1 Nominal Features Recognition

A process planning system must include algorithms that provide for nominal feature recognition. Also included should be an interface for manual picks by the user to associate faces and edges of the part to manufacturing features. These feature shapes (sets of faces and/or edges) will be represented by data structures which will support the display of the faces or edges, query by recognition algorithms and editing of the entities that make a feature shape.

Requirements:

The system shall:

2.1.1.a - Graphically highlight in color recognized features. Optionally, also provides list of features and hierarchy of features recognized from nominal shapes of the part definition.

2.1.1.b - Graphically highlight in color all geometry not contained in recognized features.

2.1.1.c - Graphically highlights in color those shape features affected by non-shape feature considerations. Optionally, also lists associations made of non-shape considerations on the recognized shape features.

2.1.1.d - Provide a user interface to facilitate interaction by user to identify, mark (capture) additional significant shape features.

2.1.1.e - Query of feature shape entities shall support:

- Area of face and length of edge.
- Faces of the feature shape.
- Edges in a face.
- Calculate intersection between faces.

2.1.1.f - Editing of feature shape entities shall support:

- Adding a face or edge to a feature shape.
- Deleting a face or edge from a feature shape.
- Adding a new feature shape and deleting a feature shape.
- Modifying a face or edge of a feature shape from Boolean operations, tweaking of geometry and making a face or edge extend infinitely.

2.1.1.g - The following techniques shall exist for identifying feature shapes:

- Manual picks of faces or edges by the user using an interactive selection method. The user will select the type of feature shape he is going to identify and the system will check to verify the selection.
- Topological matching techniques that look for patterns which make up a feature shape. A solid modeling kernel should be used to search the topology of the part looking for hole shapes, pockets, steps, notches and other defined patterns.
- Convex Hull of the entire part and sets of faces and edges should be used to determine faces of protrusion features.
- The Voronoi Diagram should be used at cross sections of the part to determine what faces and edges make up feature shapes of complex interacting features.
- Reading a STEP file for design features.

2.1.2. Raw Material Selection

This task shall select the raw stock shape and material so that the material specifications are satisfied and the volume requirements are met. Further, it might have to satisfy other requirements such as easily accessible locating and clamping surfaces and conforming to standard raw stock shapes.

Requirements:

The system shall:

2.1.2.a - Provide choice of nominal raw material stock - bar, sheet, vendor casting, etc.

2.1.2.b - The minimum raw stock shall be based on requirements from the Product Definition data.

2.1.2.c - The raw stock shall be created manually by the user by specifying parametric values of common raw stock shapes.

2.1.2.d - The raw stock shall be created automatically for the convex hull of the part. Simplification of the convex hull will usually be required to remove faces and conform to a standard shape of raw stock.

2.1.3. Tolerance Analysis

This task shall analyze the tolerance specifications on the part and convert them into specifications on the recognized manufacturing features.

A related task to Tolerance Analysis is Surface Treatment Design Requirements, which should be extracted from the product definition model and implicit manufacturing features. Surface Treatment Design Requirements shall be created and used for process selection.

Requirements:

The system shall:

- 2.1.3.a - Display in graphical form, a chart showing analysis of the tolerance specifications on the part with the reference surfaces of identified feature(s) reflected.
- 2.1.3.b - Provide an option to modify or add additional features to the feature list recognition cycle to verify the features defined/extracted on the part and the tolerances specified on the part.
- 2.1.3.c - Provide an option to specify tolerances as interfeature, intrafeature, or hybrid combination.
- 2.1.3.d - Display before and after results of nominal features recognition requirement and ability to reset to prior starting conditions.
- 2.1.3.e - The process planning system shall be able to extract all tolerances of size of a feature and record that tolerance into the manufacturing feature. A link to the design tolerance and the manufacturing feature tolerance specification will be maintained so that if the design tolerance changes the manufacturing feature definition can automatically change with the permission of the user.
- 2.1.3.f - Datum reference surfaces will be extracted and recorded for each manufacturing feature. When no explicit datum is called out for a feature, tolerance stack up will be used to determine datums for the feature.

2.1.4. Detailed Feature Creation/Association

The Macro Planner shall communicate feature shapes to appropriate Micro Planners. The Micro Planners shall use the feature shapes identified to create manufacturing volume features which represent the volume of the material to be removed from the stock to process that feature to the defined state. The documentation of selected features which are represented in the NC part program and manufacturing strategy should be recorded in the manufacturing script repository, but must be accessed and recorded through the Macro Planner. These features must also be linked to the higher level features identified in the Macro Planner function.

Requirements:

The Micro Planner system shall:

- 2.1.4.a - Volumes shall be created by the following techniques:
 - Manual – user created via Boolean operations.
 - Automatic – 2 1/2D sweep of a face.
 - Envelope algorithm - closing off a set of faces. The solid model kernel shall provide this capability. If the faces can't be closed by the solid model kernel, the convex hull of the faces will be used to create additional faces until the faces can be closed off.
 - Voronoi Diagram - will be used to create offset curves of a cross section which then will be swept into a volume. Different layers of Voronoi Diagrams will be merged to determine the combined offset profile of several features whose volumes interact.

2.2 Manufacturing Plan Optimization

This process optimizes the manufacturing plan across the entire routing. This process documents the capability assessment which is the technical evaluation of the complete process defined as required to manufacture the product. This process examines and recommends whether a product should be made in house, initiated and partially completed by a vendor, or bought in final from a vendor. As part of the make/buy decision, this process analyzes the vendor pool capability to meet design criteria, schedule requirements, cost effectiveness, security requirements, government safety and health regulation, government environmental regulations, and government transportation regulations.

Requirements:

The system shall:

- 2.2.a - Record assumptions electronically and link them with the manufacturing plan.
- 2.2.b - Record the capability assessment grade, creator, and rationale for grade.
- 2.2.c - Request validation or additional information for a RFQ to the applicable Micro planners, for review and feedback on manufacturing and testing capability.
- 2.2.d - Record Micro planner feedback, in the manufacturing assumption set, concerning limitations, additional information needs, etc.
- 2.2.e - Record attributes and values from alternatives considered in making determination.
- 2.2.f - Identify and retrieve applicable vendors from the manufacturing resource base and identify product center, business unit(s) and work cell(s) suitable for part sourcing.
- 2.2.g - Generate a complete sequenced listing of processes and machine tools for production of the part.
- 2.2.h - Automatically analyze part manufacturing feature requirements against established processes and machine tools available in the resource base considering manufacturability rules and conditions capable of being satisfied.
- 2.2.i - Provide a total cost minimum estimate across identified alternatives.
- 2.2.j - Flag all features outside of process-certified limits for feedback to CAD design system to notify customer.
- 2.2.k - Itemize all major discrepancies/deviations and provide in a graphical display for design and customer use.

3. PROCESS SELECTION AND ORDERING (AS-IS/TO-BE DESIGNS)

This process starts with identified processes and alternatives and generates a globally optimized manufacturing plan which determines manufacturing features, raw material form, routing, detailed routing, operation sequence, anticipated costs, quality and manufacturing cycle duration. Manufacturing plans include the operational plans, Bill of Material, and as-is and to-be features states for each process step. The sequence plans will be used for scheduling, capacity planning, cost estimating, material requirements planning (MRP), and by the shop floor. The high level plans (routing and sequence plan) will compile detailed planning data from appropriate micro planners to provide a view of the total plans and information necessary to manufacture product. Manufacturing plans will be created, modified, tested, approved, and configuration managed by the Manufacturing Planning system.

Requirements:

The system shall:

- 3.a - Generate the Bill of material (BOM) and Routing, including a unique identifier and effectivity dates, with their attributes and associations (these elements may be generated by utilizing standard plan items, modifying existing plans, or creating new plans):
- 3.b - Store process sequence, Routes, Bill of material, and operation plans and their associations in an object oriented data repository for use in external systems such as Shop Floor Control.
- 3.c - Maintain an audit trail of the manufacturing plan versions.
- 3.d - Permit only one active production version and at least one other version for planning purposes for the bill of material or route. When a new version of a bill of material or route is adopted, the previous version will be replaced. Only production versions will be released for use on the shop floor.
- 3.e - Create a route that is not attached to a product in order to support ad-hoc rework.
- 3.f - Automatically determine and use the active version when a user enters any identification number for an item. The version will not need to be entered by the user, but may be if desired or to specify a version other than the one that is active.
- 3.g - Provide rapid retrieval of all process identifiers and specific attributes required to support queries and development of manufacturing plans for new products.
- 3.h - Retrieve standards by either group technology classifying attributes, feature lists or via a menu for each manufacturing plan item.

3.1 Develop Resource Base

This process defines an Enterprise Resource Base that maps manufacturing capabilities available of the agile, distributed enterprise to manufacturing features (including in-process features) appearing in products that can be supplied. The resource base maps operations and supporting tools or equipment groups to basic features and tolerances. For each process operation, the resource base defines an equipment class, its capability, number of units (machines), support requirements (tapes, fixtures, etc.) and costs, work volumes, location and cost (per unit of time).

Requirements:

The system shall:

- 3.1.a - Identify, retrieve and display the processes with capabilities for a manufacturing feature at specified tolerance levels as documented in electronic product definition files.
- 3.1.b - Provide a user interface to retrieve similar information based on engineering studies.
- 3.1.c - Provide user interface to maintain and enhance feature libraries, resource description and linkage maps as required.
- 3.1.d - Provide identity for mass update of candidate plans affected by resource update.

3.1.1 In-Process Feature Selection

This task shall examine a set of manufacturing processes for operations required to process each recognized shape and non-shape feature. General constraints shall be recorded such as the order of a feature process because of access and locating surfaces not yet processed. Examining feature processes may create additional requirements and in-process features not found in the finished part design. Examples of these features include the intermediate geometry of features during roughing and finishing cuts which span more than one operation. Another example, is locating and clamping features that are required to manufacture the part. Here a face, diameter, hole or a set of faces may be required for holding or locating the part during machining operations. These features will ultimately be removed in later operations.

Include with In-Process Feature Selection is ordering of feature generating processes. This task specifies a partial ordering on the process sets selected for the features, based on tolerance relationships between features and the geometrical, technological, and engineering constraints that must be satisfied for each process.

NOTE: In process features to decompose excess stock are determined in the appropriate Micro Planner. Micro Planners will validate Macro defined features in the detailed Product/Process Design phase.

Requirements:

The system shall:

3.1.1.a - The user shall have the capability to specify feature processes by selecting from a list of candidate processes for that feature. The process planning system will guide the user in specifying parameters to define the processes of a feature and it's constraints with other features. This approach is similar to standard methods used in variant planning systems.

3.1.b - A generative Macro Planner shall include the capability to automatically specify feature processes in the following ways:

- A generative Macro Planner shall be able to analyze feature definitions and create a set of manufacturing processes. Feature process constraints will be recorded.
- A generative Macro Planner shall be able to reason hypothetically about the set of processes to manufacture a feature. The alternative lines of reasoning generated by a generative Macro Planner will be maintained by the system. If a process combination violates a constraint maintained by the system, the line of reasoning shall be marked invalid.

3.1.2 Feature And Process Mapping

For each manufacturing feature there should be a set of candidate processes or operations available to support manufacturing. This task assembles a sub-set of processes available to manufacture the desired feature. The mapping of processes to features is an important concept in the definition of an Enterprise Resource Base.

3.1.3 Candidates Pruning

For each feature there may be one or more processes or operations possible that would produce the required feature. If more than one process is available, a method to eliminate the least desirable or unacceptable processes must be available. Automatic generated results may be reviewed and can be either updated during the reviewing function if found to be lacking required constraints.

3.1.4 Machine Tool Selection

This task shall select a candidate set of machine tools that are capable of performing the operation for generating the feature. Initially, this task shall be performed manually by the user and eventually by an expert process planning system. Decisions to be made are:

- Ensure that the machine is capable of generating the relative motion(s) necessary for the operation(s) being considered.
- Test whether the travel limits of the axes and other size considerations are adequate.
- Ensure that the accuracy of the machine are adequate.

3.1.5 Machine Tool Representation

The machines that are to be considered as possible candidates for feature material removal must meet certain criteria in order to perform the required operations. In order to perform this task a representation of machine characteristics will be needed. The following information will be essential for machine tool representation:

- Kinematic structure of machine including the degrees of freedom between the tool/probe and table (number and type of axes) and the number of coordinated axes (simultaneous versus non-simultaneous movement).
- The work volume, table size, range of motion on the axes and other parameters constraining the size of the workpiece to be manufactured.
- Spindle horsepower ratings, spindle speed ranges, and axes feed rate minimum/maximum ratings.
- Attachments which can be mounted on the machine, capacity of tool magazine and similar information.
- Accuracy and repeatability capabilities of machine.
- Machine controller and its capabilities.

3.1.6 Potential Machine Candidates For Each Operation

For each feature there should be a set of candidate machines available to support manufacturing. This task assembles a sub-set of machines available to manufacture the desired feature.

3.1.7 Preferred Machines Associated With Each Operation

For each feature there may be one or more machines that would produce the required feature. If more than one machine is available, a method to eliminate the least desirable machines must be available. Automatic generated results can be reviewed and updated by the reviewing function if found to be lacking required constraints.

3.1.8 Set-Up Planning

The Macro Planner system determines a set of processes associated with each feature, a set of operations with each process and a set of machines with each operation. The information assembled by the Macro Planner system is now in a hierarchical feasible space and ready for further detailed analysis to determine preferred and alternate processing techniques.

3.2 Generate Routing

This process provides the identification and sequencing of all operations necessary to manufacture a product or to receive material from a vendor, and identifies the resource group and manufacturing center required to perform each operation. It also associates the routes to a product in the correct sequence. There are three types of routes that can be associated to a product: primary, alternate, and rework. A primary route is the preferred route for a product. It is always associated first. An alternate route can be associated to a product for a primary route if a resource or capacity constraint may prevent the use of the primary route. Rework routes can be either planned or ad-hoc. When the rework can be predicted ahead of time, it will be incorporated in the original plan. When a part is non-conforming, and the necessary rework was not preplanned, an ad-hoc rework route can be specified to permit additional work.

Requirements:

The system shall:

- 3.2.a - Attach a route to more than one product.
- 3.2.b - Specify multiple routes, in a specified sequence, for a product.
- 3.2.c - Specify a manufacturing center for a route to designate where work is performed.
- 3.2.d - Uniquely identify routes (route-id).

3.2.e - Specify the Primary, Auxiliary, and Support resource groups required for a route operation.

3.2.f - Specify a route version and effectivity dates.

3.2.g - The same route identifier may not be repeated for a particular product.

3.2.h - Ensure that an operation occurs on a specific route only once. An operation may occur more than once for a given product, as long as a different route is specified each time the operation is repeated.

3.2.i - Define and assign alternate and rework routes. Alternate routes must return to a primary route. Rework routes may begin at any operation within a route and must indicate which route operation to return to on the primary route.

3.2.j - Define the planned yield at each product route operation. Standard yields for an operation may be used in lieu of creating a yield for a specific product route operation.

3.2.k - Maintain the sequence of the operations contained within a route.

3.2.l - Maintain the route, route version and route operation entities with their associated attributes including the operations and their sequence within the route in the Macro Planner.

3.2.m - Associate routes to a product in sequence.

3.2.n - Record all routes for a product, with their sequence in the Macro Planner.

3.2.1 Associate Resource Group to Route-Operation

This process provides the information required to identify primary, auxiliary and support resources and facilities required to perform manufacturing and testing. Resources include but are not limited to people, machine tools, gages, NC Programs, and other equipment.

This process is accomplished by:

Capability Analysis assessment is performed for bottleneck or critical resources. A Capacity Analysis Assessment is an evaluation of the capacity of one or more resources to meet schedule requirements during a specified time. Capacity planning data is most often used to evaluate machine capacity.

Forecasting manufacturing software, tool, gage, and container design requirements;

Performing a capability assessment for the selected resource group;

Providing resource requirements to Manufacturing Resources.

NOTE: Shop Floor Control data from the Production Requirements and Scheduler provide the data necessary to fulfill these requirements.

Requirements:

The system shall:

3.2.1.a - Display load profile data on a selected resource group as required from the Capacity Planning System.

3.2.1.b - Record and file resource requirements, for all releases manufacturing plans in the manufacturing script repository for access by other systems.

3.3 Generate Bill Of Material

This process identifies a need for a bill of material, creates products needed as components in a bill of material, and creates a Bill of material. This includes identifying all the components used in the bill as well as assigning an identifier to the bill. This process also associates a bill of material with a product-route-operation.

The bill of material (BOM) is a product structure model, which identifies the components (from lowest level of identifiable components and raw materials to the highest applicable level component or assembly) making up a higher level component or assembly. This process includes three types of bills of material - assembly, additive, and separate bills. An assembly BOM is defined as a list of parts, components, raw material, expendable tooling, and hardware, and the quantities of each required to make any part, subassembly, or shippable product. A separate BOM is used to track the components separated from a lot, and an additive BOM is used for tracking components which are added to a lot based on either the current quantity of the parent product lot or on a target quantity for the parent product lot. Quantities in bills of material can be specified as each, fractions or weights.

The Generate BOM process provides a product specific BOM which is then associated with a product routing at a specific operation.

The generation of a BOM is accomplished by evaluating existing product definition information, BOMs, product assumptions, and associated or similar BOMs. The BOM can be created by copying and modifying an existing BOM, using or modifying a generic BOM, or creating a new BOM. BOMs may be modified when plant reviews, customer reviews, and/or experience identify necessary changes. The same BOM may be used on more than one plan.

Requirements:

The system shall:

3.3.a - Enter single-level BOMs that can be attached at a product-route-operation. The attaching of a BOM at a product-route-operation is called a BOM junction.

3.3.b - When entering components on an add or assembly BOM, must have the ability to specify at what operation the component needs to be when called for use in the execution of the bill for the product it is being added or assembled into. Conversely, for a separate bill, it needs to specify the operation where the component's lot should be created, upon execution of the BOM.

3.3.c - Identify an item as a lot or inventory item in the BOM (i.e. quantity per).

3.3.d - Identify components which should come from a kit in the BOM. The BOM is used to kit components prior to actual assembly so that components travel and are processed together. This means that a BOM may be used at an operation to kit (bring the components together as a group) and at an operation to assemble (actually assemble the components into the product).

3.3.e - A manufacturing plan for a product may reference many bills. Each bill may contain one or more components.

3.3.f - Identify substitute and alternate products. An application of this is for vendor material use based on certification requirements. Substitute components will allow higher certified products to be used in place of a lower level product.

3.3.g - When entering component on an add or assembly BOM, must have the ability to specify at what operation on the component's route the product needs to be when called for use in the execution of the bill for the product it is being added or assembled into. Conversely, for a separate bill, it needs to specify the product-route-operation where the component's lot should be created, upon execution of the BOM.

3.3.h - Provide the user with multiple views of BOM information to support planning, scheduling, and associated data collection requirements. These include the ability to view single level BOMs, to implode (display all the products a particular component is used in), and explode (display all the components and their quantities associated with a particular product) product structures.

3.3.i - Record restricted use, acceptable uses, and units for products being created.

3.3.j - Record quantity of components, bill-of-material version, creator, create date.

3.3.k - Identify a bill of material as additive, assemble, or separate.

3.3.l - Export bill of material information, including all bill of material attributes, bill of material version attributes, BOM version component attributes and attributes for additive, assemble, or separate bill of material.

3.3.m - Sequence bills of material within a product route operation.

4. PLAN/PERFORMANCE ANALYSIS

This process evaluates and grades manufacturing plans with respect to actual manufacturing performance. Evaluations are conducted with data collected during operations.

This process is accomplished by:

Comparing the as-built product information with the plan.

Evaluating actual versus standard times, conformance of manufacturing execution to the manufacturing plans, quality of resultant product, product cost, and process capability information.

Assessing external factors, such as material quality or equipment problems, which may have influenced the resultant product quality.

Identifying any problems, such as excess stock, unstable or unsuitable material conditions, high non-conformity from an operation, excessive time required to complete an operation, and/or high cost.

Recording the results of the evaluation.

4.1 Create Manufacturing Plan Evaluation Criteria

This process creates the manufacturing plan evaluation criteria for a manufacturing plan category

Requirements:

The system shall:

4.1.a - Establish the criteria to be used in scanning plans for further evaluation. Items to evaluate include, but are not limited to:

Labor time by operation	Amount of waste generated (material)
Equipment by operation	Amount of material estimated and consumed
Overall cycle time	Version to plan (including tooling, NC, etc.)
Operational and overall yield	Total Costs (labor, material, tooling, etc.)
Operational deviations	Waste reprocessing (amount x cost)
Operational reworks	Machine cost by hour
Percent of non-valued-added time	

4.2 Evaluate Manufacturing Plan Performance

This process evaluates a manufacturing plan, in order to identify strengths and weaknesses, by comparing the as-built product information with the plan.

Requirements:

4.2.a - Individually assign and control responsibility for plan evaluation.

4.2.b - Record comments associates with evaluating the plan.

4.3 Identify Alternatives

This process identifies alternatives to segments of the manufacturing plan which might improve the plan's schedule, cost, and/or quality performance.

This process is accomplished by:

Identifying and prioritizing alternatives for a portion or portions of a plan, which may improve overall plan performance.

Performing analyses, such as a complete material evaluation including laboratory and metallurgical analyses.

Assessing manufacturing history (as-built) against the plan.

Developing alternatives for plan items based on the results of the various analyses.

Requirements:

The system shall:

4.3.a - Record identified alternatives with the manufacturing plan version.

4.4 Assign Grade

This process assigns a grade to each plan which has been evaluated. This process is accomplished by assigning a grade based on the results of a comparison of performance prediction and actual results, external influences, and the inherent quality of the resultant parts.

Requirements:

The system shall:

4.4.a - Record an evaluation grade for a manufacturing plan version.

4.4.b - Associate the grading criteria used and associated grading criteria values to the manufacturing plan version.

4.4.c - Record external influences which impacted the plan grade.

4.4.d - Prepare a total cost compilation for actual performance compared to the estimated total cost for the plan.

4.5. Establish Manufacturing Plan Business Methods

This process develops and maintains manufacturing business methods (standard plans) for all elements of the manufacturing planning hierarchy. Business methods include guidelines and standards that may apply to how a part is made or inspected, or how systems that control manufacturing are implemented including:

Manufacturing and testing methods;

General requirements from Quality, HSEA, and Waste Management;

Developing manufacturing and standard system templates (i.e. standard routes, operations, operator instructions); and

The definition of all operations.

The business methods process is accomplished by:

Maintaining a standard change request log;

Analyzing requested changes (frequency, type change, and grade) for impact on the total manufacturing stream;

Determining if changes to standards are needed, achieving consensus requirements for change, and coordinating implementation for accepted changes;

Developing and maintaining standard machinability data by material type required to support the standards, including cutting tool radius and grade, stock removal schedules, library of fixtures, tool holders, and inspection and material removal methods; and

Developing standards using existing elements, including, the use of work measurement standards data to develop standard steps.

NOTE: The Micro Planners will create, maintain and make this data available for Macro Planner use.

Requirements:

The system shall:

4.5.a - Define elements of the manufacturing plan as standards.

4.5.b - Support keyword searches through test data associated with the manufacturing control method document.

4.5.c - Develop and maintain standard machinability data. (Micro Planner)

4.5.d - Define and use a generic route. A generic route is a type of standard route which may be used in compiling product-specific routes. Generic routes contain a subset of the attributes for a product-specific route. At a minimum, the generic route includes the operation and the operation sequence. Standard routes are used without modification, generic routes are copied, and additional details are added.

4.5.1 Evaluate Requirements For Mfg Plan Business Method

This process receives external requirements, requests from manufacturing or support organizations, or the results of monitoring; and evaluates if they should be incorporated in a new manufacturing planning business method or a version to an existing manufacturing planning business method.

Requirements:

The system shall:

4.5.1.a - Record the portion of the product mix or feature list to which a standard applies. The portion of the product mix may be defined by a set of characteristics which apply to certain combinations of values of the group technology classifying attributes or to specific features and materials.

4.5.1.b - Record request for a standard.

4.5.2 Identify Affected Mfg Plan Business Method

This process determines which guidelines and standards are affected by a request for a manufacturing business method.

NOTE: This capability will support engineering evaluations which may be conducted as part of Enterprise Modeling.

Requirements:

The system shall:

4.5.2.a - Search and retrieve standards matching the Group Technology classification scheme or features list.

4.5.2.b - Record the team creating a standard.

4.5.2.c - Determine what type of standard is needed.

4.5.3 Generate Mfg Plan Business Method

This process creates or revises a specific guideline or standard. This includes generating a standard route, bill of material, detailed plan operation, manufacturing planning control method requirement or operation.

Requirements:

The system shall:

- 4.5.3.a - Uniquely identify each route operation and step and indicate if it is a standard and maintenance version control on the standard.
- 4.5.3.b - Control authorized access for definition of standards, routes, operations, and steps.
- 4.5.3.c - Define and store within the Manufacturing Planning system standards for each planning category.
- 4.5.3.d - Define and store within the Manufacturing Planning system standard routes for associated operations.
- 4.5.3.e - Compute average process cost and duration for defined standard routes and operations for similar parts.
- 4.5.3.f - Temporarily redefine process and computer average cost per duration for selected similar parts above.

4.5.3.1 Generate Mfg Plan Standard Route

This process generates standard routes including creating the route, determining the primary, auxiliary or support resource group for each route operation, and associating the resource group to the route-operation.

A generic route is a type of standard. A generic route may be used for new work, with detail added to the route as experience is gained on manufacturing the product. The generic route would be copied from a list or table of standard routes for a specific product. This process creates any of the three types of standard routes (primary, alternate or rework). This process provides the information required to identify primary, auxiliary resources and facilities required to support manufacturing and testing. Resources include people, tools and gages, Manufacturing software and equipment.

4.5.3.2 Generate Mfg Plan Standard BOM

This process generates a standard BOM, associates components, and creates any products needed as components which do not already exist in the plant item master.

Requirements:

The system shall:

- 4.5.3.2.a - Record restricted use, acceptable uses, and units for products being created.

4.5.3.3. Gen Standard Manufacturing Resource Events

This process generates standard resource events which do not affect the status of a resource. Manufacturing Resources is responsible for creating standard resource events which affect the status of a resource. Examples of manufacturing plan standard resource events include: Elapsed time verification, and data collection for a resource that needs to be included in a lot.

4.5.4 Generate Operation

This process generates all operations including standard operations. A standard operation is an operation which has standard step containing a sequence of manufacturing plan operation detail items. A standard operation has been agreed upon by affected organizations.

Requirements:

The system shall:

- 4.5.4.a - Add or modify new operations (definition and any coded identity) plus maintain the date and identification of the person generating the new operation.
- 4.5.4.b - Define a supporting character description (operation name) for an operation identifier.
- 4.5.4.c - Provide access control for adding, modifying or deleting operations.

4.5.5 Evaluate Use Of Mfg Plan Business Method

This process monitors the utilization of developed standards and regularly reviews usage and appropriateness. This process is accomplished by monitoring standard route-operations, and Manufacturing Plan Operation Detail utilization statistics and analyzing creative plans for opportunities to define new standard routes, operations, and Manufacturing Plan Operation Details.

Requirements:

The system shall:

Retrieve elements of the manufacturing plan items using a standard.

- 4.5.5.a - Bill of material (BOM)
- 4.5.5.b - Routings
- 4.5.5.c - Manufacturing Resource events
- 4.5.5.d - Analyze manufacturing plans, (such as histogram) to detect frequency of sequenced routes or operations.
- 4.5.5.e - Analyze associated elements against standards to determine frequency of use and/or exceptions taken.
- 4.5.5.f - Record the request for a standard.

5. PROCESS DOCUMENTATION AND CONFIGURATION CONTROL

This process sets the criteria and need to maintain a configuration management system for released product manufacturing plans. It sets effectivity dates and maintains linkage to physical product in-process. The Macro Planner must compile and provide process documentation for critical manufacturing data including the Route, Bill of Material, rolling and supporting equipment needed. The Macro Planner shall incorporate critical elements of detailed planning data from the Micro Planner including cut parameters, NC program identity, volume decomp features and setup sheets.

Requirements:

The system shall:

- 5.a - Provide configuration control and archive all elements of the manufacturing plan and manufacturing planning business methods.
- 5.b - Provide an approval and release mechanism to assure appropriate plans are utilized to manufacture product.
- 5.c - Highlight portions of manufacturing plan that have not been approved.
- 5.d - Provide effectivity data for all manufacturing plans and business methods.

5.1 Evaluate Comments

This process supports the review and evaluation of comments received during the review cycle. These evaluations result in modification to the manufacturing plan or the Manufacturing Plan Business method or notation of why comments are not incorporated after which the approval item must be reviewed again.

Requirements:

The system shall:

- 5.1.a - Identify the Manufacturing Plans that are affected by comments received.
- 5.1.b - Notify reviewer, via electronic mail, that comments were not incorporated in the Manufacturing Plan.

5.2 Determine Affected Manufacturing Plans

This process reviews approved Manufacturing Planning Business Methods and identifies the Manufacturing Plans which may need to be revised as a result of the new standard.

Requirements:

The system shall:

- 5.2.a - View the plans affected by a manufacturing plan business method.
- 5.2.b - Produce History of Changes for Summary
- 5.2.c - Produce History of Changes for Operations
- 5.2.d - Store - Total Plan or Partial

5.3 Archive Manufacturing Plan

This process establishes the rules for and archives manufacturing plans and associated information. Archiving of plans is based on rules established for each category of planning.

Requirements:

The system shall:

- 5.3.a - Establish criteria for archiving plans, either manually or automatically, based on whether or not a plan is to be evaluated.
- 5.3.b - On archival, maintain association between order, purchase order, product and plan.
- 5.3.c - Establish criteria for purging (deleting) plans from current/historical base.
- 5.3.d - Archive subsets based on aggregate objects managed by the configuration management capability.
- 5.3.e - Provide an on-line catalogue of archived enterprise descriptions.

Appendix A.

Glossary of Terms

activity A single process within a process plan (e.g. a drilling activity, a setup activity)

Application Protocol (AP) An application Protocol (AP) is a constraint subset of STEP intended to define the information requirement of one specific domain (e.g., "Configuration Control Design of Mechanical Piece Parts" or "2D Drafting"). STEP is so all inclusive that no vendor is expected to implement all of STEP. The use of APs coordinates these partial STEP implementations.

BREP (Boundary REPresentation) Solid Model A complete definition of the geometry and topology of a solid. The definition is in terms of faces, edges and vertices, which have associated surfaces, curves and points.

class A set of objects that share a common structure and a common behavior. The terms class and type are usually (but not always) interchangeable; a class is a slightly different concept than a type, in that it emphasizes the importance of hierarchies of classes. A class encompasses both data and methods.

Computerized Numerical Control (CNC) A computer that controls a machine tool.

convex hull A volume enclosed by a set of faces which meet only at convex angles..

design feature A region of a part (e.g. a slot, hole, pocket) that is a basic element in the design of the shape of a part or used capture some design intent.

design for manufacturability The process of designing a product with manufacturing considerations in mind.

feature The make, structure, form, or outward appearance of a portion of a part. Holes, slots, pockets, shafts are examples of features.

feature-based solid modeling A complete definition of the shape of a part using features as basic building blocks.

feature recognition A technique used in manufacturing planning systems to identify and extract features from a part model by examining the geometry and topology of the solid.

form feature (see Feature above).

Industrial Application Protocol (IAP) An Application Protocol developed and used by industry without formal approval by the STEP community.

knowledge based system Sometimes referred to as an expert system. In artificial intelligence, a system that processes information pertaining to a particular application and performs functions in a manner similar to that of a human who is expert in that field; a knowledge based system can solve problems by drawing inferences from a collection of information that is based on human experience and problems the system has previously encountered.

machine code Code that is used to represent the instructions in an instruction set. In this domain, machine code refers to the code used to represent NC machine tool instructions in an NC part program; or CMM instructions in a CMM part program. NC machine code is usually represented using the EIA standard Variable Block Format.

manufacturing feature A basic element of a part which results from distinct manufacturing processing.

manufacturing plan A process plan representing set of operations, bill of material, instructions and information needed to manufacture a part. A manufacturing plan for machining includes high level operational plans, setup plans, cutting plans, and NC process plans.

NC process plan A process plan representing instructions and information needed to complete an NC part program. An NC process plan includes low level operational plans, setup plans, and cutting plans within the scope of a single NC part program request.

NC part program A set of instructions (machine code) that controls a numerically controlled machine tool. The NC part program is the final instruction set that is used to control the NC machine tool.

NC program Synonymous with NC part program (See NC part program)

object An object is an instance of a class, containing the data-interface implementation. An object has state, behavior, and identity. The structure and behavior of similar objects are defined in their common class. The terms instance and object are interchangeable.

object-oriented programming A method of programming in which programs are organized as cooperative collections of objects, each of which represents an instance of some type, and whose types are all members of a hierarchy of types united via other than inheritance relationships. In such programs, types are generally viewed as static, whereas objects typically have a much more dynamic nature.

process definition A term that refers to all functions that define a process. These include process planning and machine coding.

product definition A term that refers to all information about a product, including its shape.

solid model A solid model is a computer representation of a physical object with the property that any point in space can be classified as either inside the object, outside the object, or on the boundary of the object. A solid model is useful because it has sufficient information to allow automation. Some simple examples are volume, center of mass, and moments of inertia. These properties can easily be calculated automatically with a solid model.

STEP (STandard for the Exchange of Product model data) The emerging International Standards Organization (ISO) standard for exchange of all data about product. STEP is the informal name for ISO 10303.

tolerance feature A type of feature used to attach tolerance information to a solid model.

topology The abstract connectivity and trimming of geometry. In the context of solid modeling, topology

Voronoi Diagram A Voronoi diagram of a set of points P in a plane and is a partition of the plane such that each region of the partition represents a locus of points that are closer to one member of P than to any other member. Voronoi diagrams are used for computing offset curves, finite element meshing, and closest distance between objects.

**Appendix B.
Publications**

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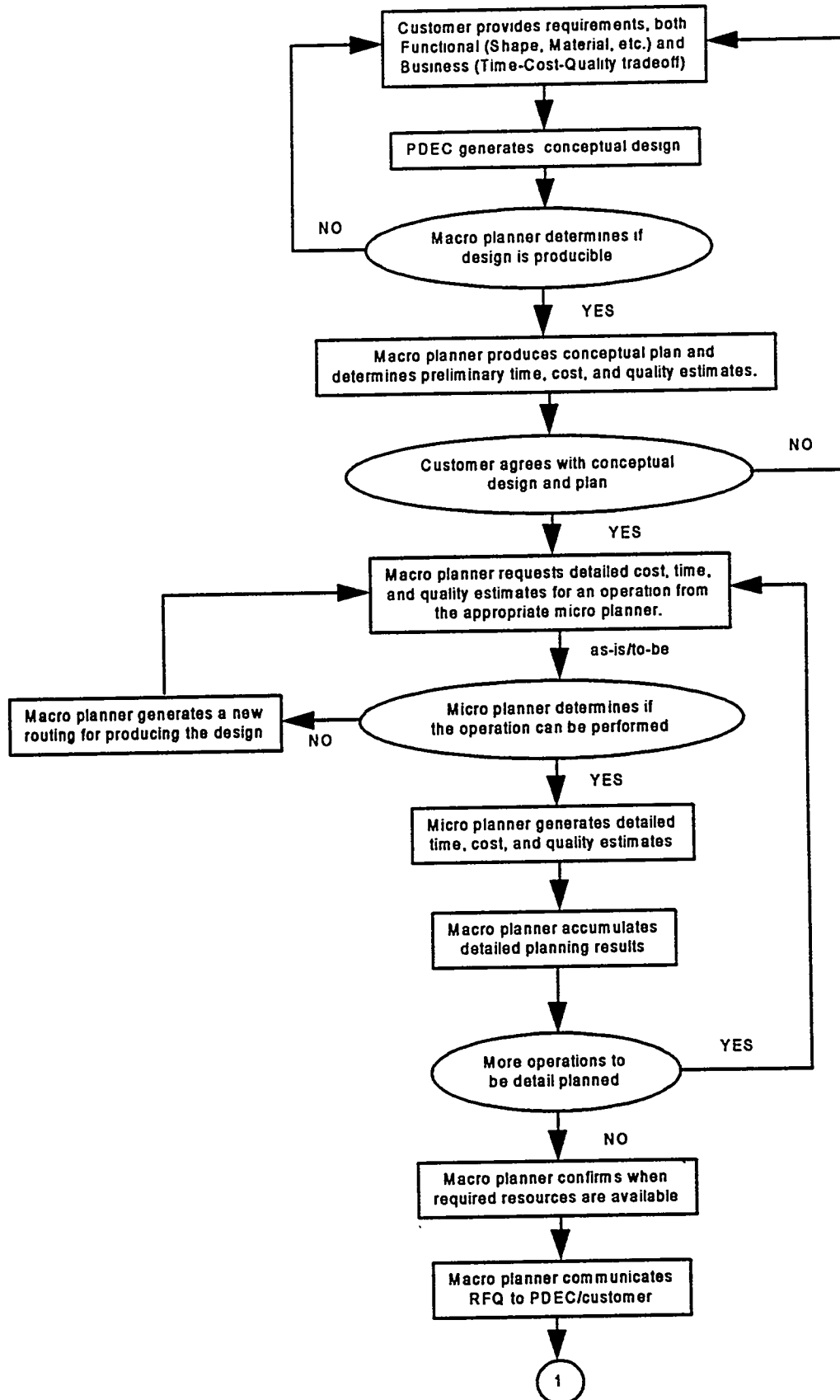
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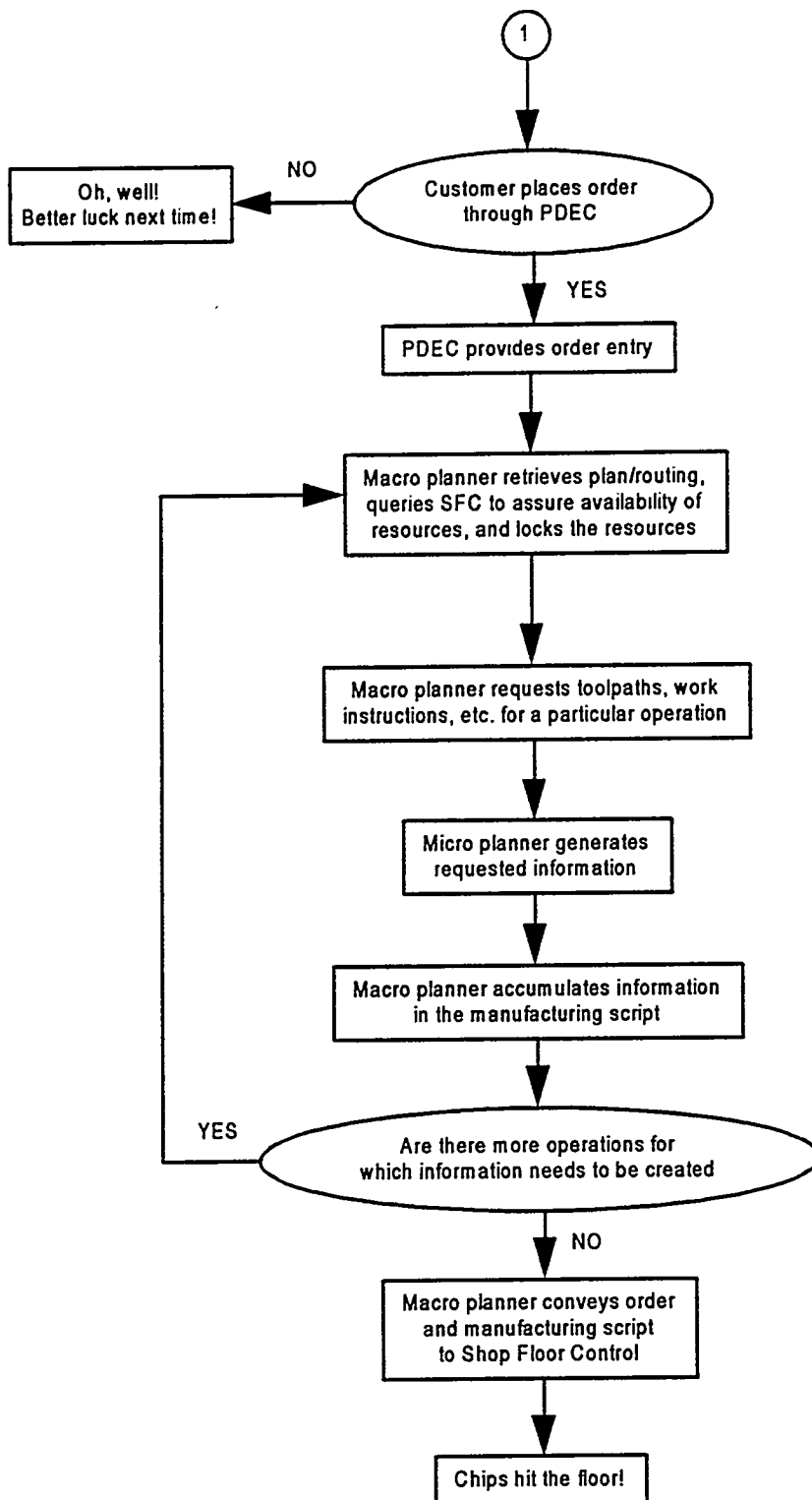
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**Appendix C.
Business Cycle Flows**





Manufacturing Engineering and Execution

Appendix D.
Macro Planner Participants

Name	Participant
Anne Backus	Oak Ridge Centers for Manufacturing Technology
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Mark Bruns	Allied Signal
Jim Butler	Allied Signal
Ben Chaudhuri	Cimplex
Derik Grant	Pratt & Whitney
Robert Hewgley	Oak Ridge Centers for Manufacturing Technology
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Mark Luce	NIST
Jan Peterson	CTA
David Prawel	Spacial Technologies
Steve Ray	NIST
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Y-12 Central Files, 9711-5, MS-8169

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Paul McKey

Step Tools, Inc.
Mike Kutcher

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Ari Requicha