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R and D CENTER LABORATORY
TECHNICAL REPORT

NO. 12703

FLEXIBLE MANUFACTURING SYSTEM HANDBOOK

VOLUME IV: APPENDICES

CONTRACT NUMBER DAAE07-82-C-4040

FEBRUARY 1983

by Charles Stark Draper Lab., Inc.
Cambridge, Massachusetts 02139

Approved for Public Release
Distribution Unlimited

U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH AND DEVELOPMENT CENTER
Warren, Michigan 48090

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Flexible Manufacturing Technology is a means to increase productivity for manufacturing environments in the middle ranges of production volume. It is effective for "one of a kind" and true "mass production" quantities. Volumes I through IV of this handbook help determine if a flexible machining system (FMS) will be cost effective for a given application. These volumes explain the configuration and procurement of a FMS, and its impact on the existing organization. The fifth volume of the handbook details the computer programs for the [illegible]

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PREFACE

This is the fourth volume in a five-volume series designed to answer the following questions concerning Flexible Manufacturing Systems (FMSs):

- Why an FMS?
- Will an FMS best serve your application?
- What problems might be encountered?
- How do you design an appropriate system?
- What is required to operate a system?

In the series, Volume I is intended to help answer broad policy questions at corporate levels. Volume II contains detailed descriptions of the subsystems that make up a typical FMS as well as descriptions of several operational FMSs. Volume III is designed to serve as a more detailed guide to planners at corporate and plant levels. This volume of appendices contains a sample request for proposal, a proposal, a glossary of FMS terms, a bibliography, and other technical material. Volume V contains user's manuals for various software packages.

LIST OF ILLUSTRATIONS

1.0 EXAMPLE "REQUEST FOR PROPOSAL"

This appendix contains an example Request for Proposal (RFP) for a Flexible Manufacturing System (FMS). With some exceptions, it is fairly general. At various points in the text, reference is made to information which would be needed to complete the RFP, e.g., a description of the parts, layout of the available floor space, etc. By including this information and making other changes, the RFP can be tailored to a specific need.

1.1 PROPOSAL REQUEST FOR FLEXIBLE MANUFACTURING SYSTEM

1.1.1 Scope

1. This Proposal Request outlines and defines the basic requirements for a Flexible Manufacturing System composed of conventional and/or custom designed equipment. It will be capable of producing (your parts).

2. The equipment, process capability, and know-how obtained as an outcome of this Proposal Request will require the supplier to demonstrate the "system's" ability to achieve its desired objectives of:

   a. Piece-part task times/production rates.

   b. Sustained quality of completed parts.

   c. Reliability of operation.

3. The "system" concepts proposed shall be designed for ease of future expansion.

4. This Proposal Request is not intended to limit the application of improvements and technological developments. Also, it should not be considered all inclusive.

5. The Buyer shall be advised of any significant design changes, machine improvements, additional accessories as they become available and might be applicable to this Proposal Request.

6. Insight into pertinent FMS issues is provided in "Pertinent FMS Issues" on page 28. This insight may prove helpful during the design of the system.

1.1.2 Definitions

1. The term "Buyer" as used in this Proposal Request shall refer to the company.

2. The terms "Seller", "Builder", "Manufacturer", and "Supplier" shall refer to the direct vendor from whom the company has a procurement order agreement(s).

3. The terms "machine", "equipment" shall be taken to mean the complete assembly (i.e., bed, column, table, control, and other integral supporting equipment or options).

4. The term "tooling" as used in this Proposal Request shall include those items that hold up or change the shape/size of the workpiece.

5. The term "delivery" shall refer to the contractual ship date established as part of the purchase order contract and work statement.

6. The term "tool change" shall mean the automatic transfer of a cutting tool from storage to active use in the spindle and return to storage through programmed command.

7. The term "part program" shall mean the information needed to command a Numerical Control machine tool in carrying out a specific sequence of machining operations. It shall consist of (specific language) source coding, cutting tool information, post-processor listing, and eight-channel tape.

8. The term "system" shall mean the assemblage of standard and custom designed machine tools, material handling system, and supporting items needed to produce the parts.

9. The term "supporting items" shall mean the necessary holding fixtures, cutting tools, part programs, process knowledge, supporting software, and miscellaneous hardware items needed for successful "system" operation.

10. The term "pallet/fixture" shall mean a piece-part registration and holding device.

11. The term "work statement" shall mean the final document defining in detail machine tool accuracies, fixture design, software requirements, etc.

1.1.3 Applicable Specifications, Standards, and Codes

The latest revisions of the following specifications, standards, and codes shall form a part of this Proposal Request. Deviations shall be identified in writing by the Seller and reviewed and accepted in writing by the Buyer.

1. General specifications ("General Specifications" on page 29).

2. NC downloading sub-system specification ("NC Downloading Subsystem Specification" on page 37).

3. Numerical Control Electronic Industry Association (EIA) Standards:

RS 227	One-Inch Perforated Paper Tape.
RS 244-A	Character Code for Numerical Machine Control Perforated Tape.
RS 267-A	Axis and Motion Nomenclature for NC Machines.
RS 274-B	Interchangeable Perforated Tape Variable Block Format for Contouring and Contouring/Positioning NC Machines.
RS 358-A	Subset of U.S.A. Standard Code for Information Interchange for Numerical Machine Control Perforated Tape.
RS 232-C	Interface between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange.
RS 431	Electrical Interface between Numerical Control and Machine Tools.

4. National Machine Tool Builder's Association Standard for Milling Machine Tapers.

5. National Fire Protection Association Standards:

NFPA No. 70	National Electric Code.
NFPA No. 79	Electrical Standards for Metal-Working Machine Tools.

6. American National Standards Institute: Programming Language.

1.1.4 Product Definition

1. The Machining System as described in this Proposal Request will be utilized to manufacture (your parts).

(Provide a description of your parts, including title, drawing number and revision, and weight.)

2. The Supplier should assume sand castings will be provided with location/mounting surfaces. The exact type and location of these will be worked out with the Buyer and the casting vendor.

1.1.5 Production Requirements

1. The "Machining System" described in this Proposal Request shall be capable of producing, to drawing tolerance, (number of) sets of parts per month on a continuing basis.

2. Production planning should be figured on a two-shift, five-day week. To adjust for vacation, holidays, personal time, etc., the above figures will be averaged over a year at (number of) available hours per month.

1.1.6 System Machining Equipment

1. Scope

The purpose of this equipment is to machine the parts within the accuracy specified in the part drawings.

2. General

a. The Seller shall be responsible for the design and shall have the choice of configurations and functional operation of the machines unless specifically limited by this Proposal Request.

b. The machines shall be engineered, designed, and constructed such that they will have sufficient strength, rigidity, and stability to meet all system requirements for: continuous operation at full horsepower, accuracy of all movements, repeatability, reliability, maintainability, and piece-part tolerances.

3. System Description

The equipment proposed is the Seller's option. Each item must have provisions for: quickly registering pallets and/or fixtures to an index table, complete cutting tool storage for planned operations, and complete part-program storage for planned operation(s).

The level of material handling sophistication proposed will be left to the Seller's option, keeping in mind the total number of operators needed. (This statement could be more detailed if the Buyer so desired.)

All fixturing, cutting tools, part programs, material handling aids, and other supporting features will be interchangeable to all system machines proposed. Such interchangeability will be achieved with minimum cost/schedule penalties.

System design shall be such that routine setup/changeover for different piece parts will be within normal operator work skills, i.e., maintenance help not required. The same criteria shall apply to interchangeability as described above.

The equipment must have the minimum specifications listed below.

4. <u>Size and Capacity (Example Specifications)</u>

a. X-Axis Stroke: 24" minimum.

b. Y-Axis Stroke: 24" minimum.

c. Z-Axis Stroke: 24" minimum.

d. B-Axis Index: 360 degrees in one-degree increments.

e. Table Load: 3,000 lbs. (Exclusive of pallet).

f. Pallet Size: 24" square minimum.
36" square maximum.
24" rectangular minimum by 36" rectangular maximum.

g. Spindle Taper: 50 NMTS S -- accept ANSI standard (proposed) "V" flange tool holders/coupler.

h. Spindle Diameter: 4" minimum.

i. Spindle Speed Range: 20 minimum - 4,000 rpm maximum (infinitely variable preferred).

j. Horsepower, Continuous Operation: 15 minimum.

k. Rapid Traverse: 300 IPM minimum.

l. Tool Changer Capacity: 60 tools minimum.

m. Tool Changes: Changer must be capable of consistent handling of all tools in regard to weights, diameters, and lengths needed to machine the parts described in "Product Definition" on page 3.

n. Feed Rates (IPM): 0.1 to 400 (infinitely variable preferred).

o. Coolant: Through the spindle is preferred.

5. Alignments and Related Requirements (Example Specifications)

a. Machine Slide Motions

- "X" Axis Movement 0.0001"/ft., not to exceed 0.0002" full range.
- "Y" Axis Movement 0.0001"/ft., not to exceed 0.0002" full range.
- "Z" Axis Movement 0.00015"/ft., not to exceed 0.0003" full range.
- Each axis, including "B" rotary motion, shall be square and perpendicular to all others within 0.0002"/ft. not to exceed 0.0004" full range.
- "B" Axis (rotary) work surface shall not deviate more than 0.0003" band checked at (four) corners and at (four) 90-degree indexes.
- Note: Camming (roll, pitch, yaw) is considered in tolerance bands defined above.

b. Indexing Unit

- Working Surface Flatness within 0.0001" in any 12" and not to exceed 0.0003" total.
- Edge(s) - All edges, symmetrical to axis of rotation to be within 0.00015"/ft.

c. Spindle

- Taper R/O - 1 1/4" from nose 0.0002" Total Indicator Reading (TIR) and not more than 0.0005" TIR 12" from nose.
- Gauge line - 0.00015" TIR.
- Face - 0.00015" TIR.
- Axial Growth "Z" Plane - After a one-hour warmup, additional growth shall not exceed 0.0005" band.
- Draft, "X" and "Y" Planes - After a one-hour warmup, additional growth shall not exceed 0.0003" band.

6. Positioning Accuracy (Example Specifications)

a. Linear Axis

- "X" ± 0.0001"/ft. not to exceed ± 0.0004" band over full range.

- "Y" ± 0.0001"/ft. not to exceed ± 0.0004" band over full range.

- "Z" ± 0.0001"/ft. not to exceed ± 0.0004" band over full range.

b. Rotary Axis

- "B" ± 2 seconds of arc.

c. Pallet Registration (if applicable)

- 0.0003" TIR.

7. Repeatability (Example Specifications)

a. Linear Axis

- "X" 0.0002" band.

- "Y" 0.0002" band.

- "Z" 0.0002" band.

b. Rotary Axis

- "B" ± 1 second of arc.

c. Pallet Registration: 0.0002" TIR.

8. Controller Requirements

a. General

The following requirements of a general nature must be included:

- Must be (desired brand) controls.

- Must be of the CNC type or equivalent and be of modular construction with integrated circuit electronics throughout. The conversion of input data into position commands including slopes and radii shall be an integral part of the control.

- Must provide fully automatic, semiautomatic, and manual operating modes:

  Automatic - Input data to be downloaded from a centralized processing center or read from one-inch wide, eight-channel tape.

  Semiautomatic - Input data to be inserted one block at a time by an interactive visual display/alphanumeric keyboard.

  Manual - Control by pushbuttons.

- Must include both linear and circular interpolation as an integral part of the control. Linear interpolation shall function in all three axes simultaneously. Circular interpolation as a minimum shall function in any two selected axes with the third axis functioning in a plane.

- Any modes, movements, coding, and functions not listed, but standard to the equipment, shall be provided.

- Able to provide axis compensation.

- Must provide sufficient part program storage to store the largest set of programs required at any one station. Part program to be automatically selected by fixture and/or piece-part interlock coding. Selection of part program must be at random and not sequential.

  Note: If a central program storage facility is proposed, each control must have sufficient storage for the largest program. All controls must have this same storage for interchangeability.

- Positive means must be provided to assure that a previous machining operation on the same part has been completed before the next machining operation can be started.

- Must have the capability to accept and execute any and all coding and/or instructions that may be required to operate the machining system by any or all software programs.

- In case of loss of electric power or other unplanned shutdown of controls, there shall not be any loss of any data whatsoever, nor any loss of synchronization for a minimum of seventy-two (72) hours.

Final controller options will be defined with typical features (capabilities) in the final specification.

9. <u>System Supporting Equipment/Features</u>

a. The system must have the capability of accepting coded pallets/fixtures from the load station(s) to the assigned machine. The coding shall be initiated either from the loaded piece part or the pallet/fixture itself. The coding must identify the following:

   - Piece part.

   - Orientation or attitude of part as presented to spindle.

   - Call out of appropriate program.

   - Safety interlock to inhibit start-up if all above conditions are not correct.

b. Each of the machines in the system shall have the interchangeability to accept all of the following:

- Pallets/fixtures.
- Cutting tools.
- Piece-part programs.

c. Machines to have chip conveyor units of sufficient capacity and speed to remove all chips generated from machining of all the piece parts.

d. Adequate chip and coolant splash guards to be furnished for all machines as required by the planned machining process.

e. Suitable work light to be furnished.

f. A flood coolant system to be provided that is capable of directing coolant flow to cutting points of all tools required to machine the parts, regardless of lengths and diameters without manual adjustments.

- A coolant recovery system of proven design shall be furnished for the operations to be performed that provides for recovery and return to the reservoir. The system must assure a constant filtered supply throughout all long-cycle operations.

g. Additional pendant or consolette to be furnished at load and unload stations if main control is located elsewhere.

- Pendant or consolette shall include, but not necessarily be limited to, the following functions:

1) Spindle start.

2) Spindle stop.

3) Emergency stop.

4) Cycle ready.

5) Pallet ready.

6) Pallet inhibit.

7) Program load.

8) Feed hold -- cycle interruption.

Note: Supplier is encouraged to recommend other features necessary for safe and efficient operation.

10. Machine Protection

a. Machine to be equipped with automatic lubrication of all slide and bearing surfaces. Wipers to be furnished on all ways.

b. Machine to be equipped with an audible warning system that can be silenced, as well as an indicating light to indicate potential lubrication failure.

c. Machine to be equipped with safety devices which will prevent operation of the machine without adequate lubrication or a failed lubrication system.

d. All lubrication reservoirs shall be provided with visual lubricant level indicators. Filler and other lubrication points shall be clearly marked with type of lubricant and any special instructions.

e. All machine motions shall be protected by suitable limit switches for maximum travel in both directions.

f. All motors shall be provided with under voltage and overload protection devices.

g. All three-phase motors will be protected against damage due to loss of any phase.

11. Machine Checkout/Acceptance (Example Specifications)

a. The builder/Seller shall furnish with his proposal a description of the methods, equipment, and procedures he will utilize to verify/assure the performance requirements described in this specification. As a minimum, this will include items covered in subsequent paragraphs.

b. The Buyer <u>shall witness</u> a preliminary acceptance check of all the machine parameters at the builder's facility before authorizing system testing. The builder will notify the Buyer, in writing (Attention: Buyer), at least two weeks in advance that the equipment is ready for inspection.

- The personnel, supplied by the Manufacturer, shall have demonstrated technical skill as evidenced by a complete familiarity with the operation of the equipment. Additionally, a thorough understanding of the principles and operation of the required test instruments is essential.

c. Alignments, Positioning Accuracy, Repeatability, and Machine/Control Function(s)

- Alignment checks will be performed with "Builder"-supplied calibrated equipment -- granite square, straight edges, electronic probes/surface gauges, cylindrical squares, indicators, test bars, alignment lasers, etc.

- Positioning accuracy and repeatability testing will be in accordance with National Machine Tool Builders Association (NMTBA) standard "Definition and Evaluation of Accuracy and Repeatability for Numerically Controlled Machine Tool" dated June, 1968.

  Note: Alternate test described in "Machine Acceptance Test Specifications and Procedures" on page 41 may be substituted for NMTBA procedure.

  Note: Should clamping of slides be used in any axis or combinations thereof, they shall not create any error in positioning or alignments.

- Machine/Control Function

  1) Logic Test - A test of the Logic section of the Controller using the test tape furnished by the Control Manufacturer will be conducted. This self-checking system must progress through its cycle without personnel intervention or interruption. An interruption designates a malfunction in some part of the system.

  2) Digit Test - A series of position commands programmed for each of the feed drives. These commands should be arranged to use each digit from zero (0) to nine (9). The distance traveled by the feed drive will be measured and compared with the Command.

  3) Function Test - The machine will be operated in each of the command modes -- manual, semiautomatic, and automatic. Input instructions will be inserted from each point of operation as applicable -- control keyboard, pendant, operator consolette.

     In addition to verifying all operational commands, checks will be made on machine protection devices/routines, safety features, and other supporting equipment/features.

- Machine Stability/Reliability

  Upon completion of the above tests and a suitable warm-up period, the machine shall be set up at separate calibration positions for X-Y-B and Z axes. It will then be made to cycle automatically under programmed control without evidence of failure or unplanned interruption for a period of (24) hours.

  During this period, the following will be exercised:

  1) Slide Motions - Individual, combined, and simultaneous movement including rotary axis and pallet transfer if applicable.

  2) Various programmed feed rates, including a minimum of 30% at rapid traverse.

3) Circular motions, both clockwise and counterclockwise. Slopes with different angular direction vectors.

4) Spindle speeds will be varied from low to high RPM. At least 30% of the running time, maximum RPM will be utilized. Frequent spindle reversals will also be included.

5) Tool changer will be exercised using tool configurations that test extremes of supplier's stated weight and size.

6) At approximately 20 minute intervals, the machine will be returned to the original calibration position and recordings taken of axis position and spindle location. Repeated readings will not exceed 0.001" true position diameter for X-Y-B, and 0.001" band deviation from original for Z.

- Machine Individual Operation Test(s)

A machining test will be required to demonstrate the machine's capability under actual programmed operation. The supplier will provide materials necessary for conducting these tests as well as facilities, cutting tools and personnel for verification of results.

1) Circular and linear interpolation

a) National Aerospace Standard (NAS) 979.

2) All canned cycles and miscellaneous functions

a) Must all be demonstrated as part of the machining on test pieces.

3) Milling (Reference "Machine Acceptance Test Specifications and Procedures" on page 41 for test piece design)

Set up spindle and slide datums - centerline of spindle on centerline of rotary unit within ± 0.0001".

Shuttle pallet and piece part (if applicable), mill 4 sides- flat -- hold opposite sides same distance from centerline of rotary unit 0.001". Bidirectional lap cut steps will not exceed 0.0003" when using a six inch face mill. (X-Axis only).

4) Precision Boring - Size and Locations (Reference "Machine Acceptance Test Specifications and Procedures" on page 41 for test piece design).

This test shall be conducted to evaluate the equipment's precision processing capability to specified tolerances.

a) The test will include at least five precision bores on each surface of a four-sided stable test piece.

These holes shall simulate precision dowel locations and precision-bore centerlines, size, and repeatability typical of the critical locations required in processing the castings.

Suggested Test Procedures

- Position first hole on centerline of rotation (per sketch side #1) -- drill, semifinish, finish final bore -- size out finished hole 1.0000" +0.0005"/-0.0000"; change all tools through changer.

- Position second hole - typical dowel hole - drill - semifinish - finish hole 0.3750" +0.00051"/-0.0000" (size out Finish Boring Tool). Change all tools through changer.

- Position third hole - typical dowel hole - repeat second hole process sequence. Do not adjust finishing tool. Change all tools through changer.

- Position fourth hole - simulates housing bore position and locations -- drill, rough/bore, semifinish/bore 3.500" +0.0002"/-0.0000". Size out finish tool. Change all tools through changer.

- Position fifth hole - simulates housing bore position and location - repeat process from hole No. 4. Do not adjust finish tool. Change all tools through changer.

- Apply typical fifth-hole process, sides 2-3-4 with tooling as specified, utilizing same tooling sequence. Finish tools not to be adjusted.

- Shuttle pallet and piece off and reposition pallet and workpiece automatically.

- Position first side. Locate slides to hole 4 position - counterbore hole 4 to 3.625" +0.0002"/-0.000", 0.250" +0.001"/-0.000" deep. Semifinish and finish bore. Size out finish tool. Change tools through changer.

- Proceed to finish hole No. 5, first side. Do not adjust finish tool. Change tools through changer.

- Proceed to counterbore 3-1/2" diameter holes on each of the remaining three sides. Do not adjust finish boring tool. Change all tools through changer.

- True position of all bores not to exceed 0.0015" True Position (TP) diameter.

- Hole size not to exceed +0.0005" from drawing dimension.

- Inspect on machine by tramming and indicating; record data for squareness, perpendicularity, hole size, location for each side, and 180-degree alignments and relationships to centerline of rotation.

- Shuttle pallet and test piece off machine. Reposition and tram bore on centerline of rotation four times. Repeatability shall not exceed 0.0003". Change all tools through changer.

- Reverify with off machine inspection. Record data.

- Analyze data for compliance to tests and equipment capabilities specified.

- Unallowable deviations to be analyzed, reviewed, corrections made and retesting suitable to verify that corrections have been attained and results are mutually acceptable.

5) Demonstrate three axes simultaneous motion by milling a circular contour of varying depth using a ball nose mill.

   Note: May be incorporated on surface of NAS 979 test piece.

6) Maximum Horsepower Test - Using a workpiece of SAE 4150 (or equivalent) steel, mounted to the work table, a straight cut of 20 inches shall be made using a Tungsten Carbide inserted tooth face mill. The diameter of the cutter and spindle speed shall be determined by the manufacturer to be suitable for making the cut with specified chip load and peripheral cutter speeds. The depths of cut shall be as required to load the spindle motor to its maximum rated horsepower. The cutting action shall be smooth and even and the finished work piece shall show no evidence of tool chatter.

7) Accessories and supporting items will be operated and performance verified.

8) Demonstrate drilling and tapping capabilities.

- Additional Requirements for Machine Acceptance

    1) The lack of suitable foundation or other environmental conditions at the Manufacturer's Plant will not be an acceptable reason for deviations from this specification.

    2) Under no circumstances will the machine be released for shipment if any component or phase of operation has not performed at an acceptable level of operation as defined in the Contract Specification.

    3) The machine will not be released for shipment with any temporary repairs or modification in effect.

    4) Acceptance for shipment of the machine will be contingent upon the successful completion of all portions of the tests prescribed herein, as witnessed and approved by the Buyer's representative.

    5) The machine shall not be shipped until released by the Buyer.

- Final acceptance of the equipment after installation at the Buyer's Plant shall be contingent upon successful repetition of the these tests.

1.1.7 Technical Assistance and Service

1. Scope

The Supplier shall provide the technical guidance and service necessary to assure the successful achievement of the Proposal Request objectives.

2. General

Technical guidance and service to be provided by the Supplier shall include but not be limited to:

a. Complete start-up services for all equipment, including technical assistance and supervision from all necessary subcontractors.

b. Technical assistance and supervision at Purchaser's plant during installation, checkout, and piece-part cutting tests. These services shall be provided for as long a period of time as necessary to meet all acceptance criteria agreed to by the Buyer and Seller.

c. Adequate training of the Buyer's employees (operators, parts programmer, maintenance, and manufacturing engineer), in all phases of equipment operation and system processing logic.

d. Monthly progress reviews on a personal basis with the Buyer during design and build phases.

A narrative type report shall be submitted by the fifth (5th) working day of the month covering the preceding month's activity. It shall include data on actual performance versus established schedules, and identify existing or potential problem areas and their proposed solutions. An updated milestone chart (or such other as may be specified) shall be submitted as an addendum to the report.

1.1.8 Cutting Tools

1. Scope

This section shall include the Supplier's effort to provide the cutting tools/holders/adapters required for successful Flexible Manufacturing System operation.

Design and documentation costs are to be proposed separately.

Manufacturing/Procurement cost to be quoted in the following categories:

a. Standard catalogue items: breakout holders, adapters, drivers, etc., separately.

b. Special Designs.

Note: This category includes "modified standards" as a subunit.

c. Cost for three (3) sets to be provided.

Note: The Buyer reserves the right to purchase elsewhere any or all cutting tools, holders, or adapters to Supplier's specifications or designs and to furnish them to the Supplier for runoff application.

2. Design Requirements

The following capabilities/features must be inherent in cutting tool/holder design(s):

a. Cutting tools, holders, drivers, and/or coupling devices shall be interchangeable on all machines.

b. A means of identification and coding of all cutting tools shall be provided and integrated with the FMS computer.

c. Assembled cutting tool units will have preset capability for radial and end-point control without sacrificing rigidity and accuracy.

d. Assembled cutting tool units will have basic lengths established from a datum point (preferably gauge line of taper) in relation to NC programming requirements.

e. Selection of cutting tools and cutting tool materials to be based on tool life, costs, process efficiency, and compatibility. Standard catalogue items to be used where practical.

   Note: Multifunction or cluster cutting tools are acceptable if process improvement(s) justify added cost.

f. Cutting-tool units shall be compatible with machine tool-changing capability relative to length, size, and weight. Manual intervention for tool change is not desirable.

g. Tool holder shanks to be (desired brand) standard and be fully compatible with spindle taper(s) and tool changer(s) proposed by the Seller.

h. Cutting-tool selection and application to minimize burrs without sacrificing total process efficiency.

i. Face milling cutters to have integral shanks with length controlled from shank taper-gauge line to point of tooth -- variability not to exceed 0.002".

j. Boring bars to have integral shanks if diameter is 0.750" or larger. Axial adjusting bars not acceptable.

k. Boring tools to have radial adjustment capability of 0.0001" diameter.

   Note: For bar shanks 0.750" diameter or less, radial adjustment of 0.0001" diameter to be an integral part of design.

l. Tools with high Length/Diameter (L/D) ratios shall be of high modulus material or structurally reinforced.

m. Boring tool system(s) selected to have capability of consistently meeting all sizes required without operator intervention except for initial sizing.

   Note: DeVlieg microbore design(s) or equivalent should be considered.

n. Tool units (face mills, boring bars) to be dynamically balanced.

o. Coolant fed through tooling proposed must not require operator intervention. Normal machine work/capability must not be sacrificed should external adapters be proposed.

p. Tap drivers to be (desired brand) or equivalent. Self-reversing units must be applied without operator intervention.

q. Vendor to specify precaution(s) taken to guard against shank contamination while tools are in changer and/or being transferred to and from spindle.

r. Design of cutting tools shall be such that no detrimental results shall occur to machined surfaces either previously machined or in the process of being machined from chips being removed or by piloting members.

3. Documentation

The following documentation requirements must be met:

a. All cutting tool designs shall conform to commercial tool industry standards.

b. Cutting tool designs and related information shall provide enough detail to enable procurement by the Buyer without additional design effort or recourse to the original design activity.

c. For each operation, a master list will be prepared. It will supply the following:

Standard Cutting Tools - Manufacturer's catalogue number and description, holders or drivers, preset data, coding data.

Modified Standard - Manufacturer's catalogue number and description, holders or drivers, preset data, coding data, Supplier's identification number(s).

Special Design - Supplier's identification number(s), holders or drivers, preset data, coding data.

d. As the process engineering for each element is completed, the associated cutting tool design and application information will be forwarded to the Buyer for review and approval.

e. Not later than three weeks after acceptance of the Supplier-provided cutting tools at the Supplier's plant, the Supplier shall deliver one (1) complete set of certified, reproducible designs and the master lists described above.

Note: Changes or revisions which develop during equipment and/or system acceptance shall be incorporated before shipment.

1.1.9 Special Tooling/Fixtures

1. Scope

This section shall include the Supplier's effort to provide the piece-part holding fixtures required for successful Flexible Manufacturing System operation.

Design and documentation costs are to be proposed separately from the cost to manufacture.

Note: The term "pallet/fixture" as used in this Proposal Request will describe a "piece-part holding fixture". At the Supplier's option, some or all pallets/fixtures may include an integral or attached base designed to interface a machine tool registering surface.

2. Design Requirements

The following capabilities must be inherent in pallet/fixture design:

a. Capable of producing units at a rate of (number of) units per month on a five-day, two-shift operation.

b. Constructed of stable materials and/or of sound mechanical construction for rigidity and long service (Meehanite preferred).

c. Must not require manual intervention for any reason during machining cycle.

d. Minimum piece-part load times with positive piece-part positioning and fast acting holding features such as: hydraulic, air, mechanical clamping and/or the application of air tools, nut runners, etc., with positive torquing features as required.

e. Efficient operating interface with special pallet handling devices.

f. When locked to machine receivers, have an accuracy compatible with the system machining process requirements.

g. Reliable operation under all conditions normally caused by machining operations such as: chips, heat, humidity, vibration, mist, dirt, and coolant.

h. No detrimental results shall occur to piece-part accuracies and machined surfaces either previously machined or in process of being machined through part registration, clamping, chip removal, vibration, etc.

i. Suitable lifting devices shall be an integral part of each pallet/fixture construction.

j. Pallet/fixtures to be coded for piece-part application with a positive "foolproof" feature.

   Note: Final decision by the Buyer on incorporation of target points and cast appendages will be made via revised piece-part drawings.

3. Design Reviews

The following requirements describe the Buyer's involvement for design approvals:

a. Conceptual light line layouts of pallets/fixtures defining all pertinent details such as: locating features, clamping units, dimensions, and tolerances for piece-part registration surfaces, are required for approval prior to finalizing pallet/fixture designs and release for manufacture.

b. Fully detailed drawings of pallets/fixtures shall be submitted to the Buyer for his review and approval no later than four (4) weeks after design completion. Approval of these drawings by the Purchaser is approval of concept only. The Supplier (Seller) is fully responsible for correct dimensions and functional operation of the pallet/fixture in the total machining system.

4. Fixture Documentation

The following documentation requirements must be met:

a. Special pallet/fixture drawings shall conform to commercial tool industry standards.

b. Any subcontractor-provided design services shall meet the intent/objectives of this Proposal Request.

c. Pallet/fixture drawings shall provide the necessary information in the design to enable procurement without additional design effort or recourse to the original design activity. These drawings shall not provide manufacturing process information unless information is essential to accomplish manufacture of an identical item by other than the original source.

d. Pallet/fixture to be permanently identified with: the Buyer's serial numbers (furnished by the Buyer), part drawing number, fixture weight, and "U.S.A.". Also necessary is identification of process operation number. Exact method (steel stamp or attached tag) to be determined with Supplier upon contract award.

e. Not later than three (3) weeks after acceptance of special pallets/fixtures at the Purchaser's plant, the Supplier will deliver one (1) complete set of certified reproducible designs. One (1) set of pallet/fixture use instructions will also be included as applicable.

5. Machining System Requirements

a. The Supplier will propose an adequate complement of special pallets/fixtures for efficient total system processing.

b. Identification to facilitate the proper machine tape program activation by the Controller, to be incorporated into the pallet/fixture.

c. Recommendations for backup pallets/fixtures and/or spare fixture components are required for maintenance reasons, including costs.

d. A master pallet/fixture for use in system set up and future calibration checks will be provided.

6. Pallet/Fixture Acceptance

Acceptance procedure and checkout to be in accordance with specifications documented in "System Process and Acceptance Test(s)" on page 26 of this Proposal Request.

1.1.10 Options

1. Centralized Automatic Chip/Coolant Recovery System

a. Scope

The purpose of a Centralized Automatic Chip/Coolant Recovery System is to collect and remove from the principal metal-cutting areas both chips and coolant. Chips and coolant would be conveyed to a unit which separates the chips from the coolant, provides for reconditioning and recirculation of the coolant, and allows chips to be accumulated and sold for scrap value.

b. General

The Seller shall be responsible for the design and shall have the choice of the machine unless specifically limited by this Proposal Request.

2. Automatic Inspection Machine

a. Scope

The purpose of an Automatic Inspection Machine is to increase both inspection speed and accuracy; maintain repeatability of measurement; and provide, when possible, data for automatic compensation of the machine tools in the Flexible Manufacturing System.

b. General

The Seller shall be responsible for the design or procurement of such equipment and shall have the choice of functional operation of the machine unless specifically limited by this Proposal Request.

c. Detailed Discussion of Proposed Inspection Machine

The Seller shall provide the Buyer with information concerning the accuracy and speed of the proposed inspection equipment, as well as its interfaces to the system, in the Seller's response to the Final Request for Proposal

1.1.11 Discussion of Special Additional Features of the Proposed Equipment

The Buyer requests information be provided in the Seller's final proposal for the following additional features or packages to be quoted in addition to the equipments proposed.

1. Accuracy Package

The Seller shall discuss the approach and means proposed to consistently obtain the required piece-part accuracy defined by the part prints. This discussion shall detail any extraordinary operating techniques, enhanced equipment accuracy and/or environmental conditions that the Seller believes may be necessary.

2. Energy Savings Package

The Seller shall discuss the energy requirements of his suggested equipment and support units, indicating features which reduce energy consumption with respect to past practice. Additional items which the Seller believes will enhance the energy savings should be included. The Seller shall also discuss methods by which energy usage will be monitored - i.e., periodic energy audits, etc.

3. Adaptive Control and Tool Monitoring

The Seller shall discuss the advantage of his adaptive control and tool monitoring hardware and software specifically addressing the following items:

- How does the hardware function?
- How are failures detected?
- What are the responses to failures?
- What are the interfaces to the machine controller and the system computer?
- How are limits set for each tool?
- What happens to the part the tool failed on?
- What is done with the broken/worn tool?

The Seller shall analyze the advantages with respect to cost of the equipment and its importance to maintaining low manufacturig cost and consistant product quality.

4. Spindle Probe

The Buyer requests that a spindle probe capable of being stored in the automatic tool changer and exhanged into and out of the spindle. randomly be included in the equipment proposed. The Seller shall include, in his discussion of the proposed probe, the following items:

a. Canned cycles to be provided in the software for the probe. The Buyer would like, as a minimum, the following cycles.

   1) Feature verification (existence, location, and geometry).

   2) Re-zero of machine for variations in fixture/pallet/part datum locations.

   3) Offset information for particular features/tools.

   4) Verification of machine tool alignment through the use of a master pallet and part trace.

b. Capabilities of the probe proposed, such as accuracy, repeatability, sensitivity, temperature stability, and stamina.

c. Recommended features to be probed, frequency of probing.

d. Production time lost due to canned probe cycles.

e. Number of probes needed for the entire system.

f. Documentation for operation and maintenance to be provided.

1.1.12 FMS Control System

The Seller shall provide a computerized control system capable of coordinating the proposed equipment successfully to obtain the desired production levels. The Seller shall discuss in detail the following items in his response to the final request for proposal:

1. Vendor, model number, and operating characteristics of the proposed computer hardware, including characteristics such as storage available, maximum number of users, remote terminal access, power loss protection and system backup.

2. Operating system to be used with the proposed hardware.

3. Interfaces to DNC/downloading computer, factory management computer, equipment controllers, inspection machine, tool room.

4. Remote terminal access to DNC system (off-line programming).

5. Tool management/tool life monitoring software.

6. System manager decision support software; discuss individual features designed to assist system manager in day-to-day operations.

7. Management information software, including status and management reporting.

8. Diagnostic and maintenance capabilities.

9. Information for loaders and tool setters.

10. Data transmission verification systems.

1.1.13 System Process Instructions

1. Scope

This portion of the Proposal Request is to define the requirements for the detailed process operating instructions necessary to achieve the system objectives.

2. General

The following types of instruction will be provided:

- Detailed Operational Planning.
- NC Part Programs.
- Fixture Application(s).
- Setup Procedures.
- System Operation.

3. Detailed Operational Planning (If Not Provided by the Buyer)

For each of the parts, a detailed process plan, showing the sequence of operations required to complete piece-part machining, shall be prepared.

Also included and/or cross-referenced will be:

- Machine process time estimates.
- Fixture usage/identification.
- Cutting tool(s) required by machining operation.
- Special instructions/cautions necessary to achieve piece-part qualification requirements.

4. NC Part Programs

The following shall be met:

a. (Desired part-programming language) shall be used. Post-processor statements should conform to the latest applicable ANSI standards.

b. For each part program:

- Two debugged paper/mylar/paper-punched tapes conforming to EIA Standard RS 227.

- Source code on either punched paper tape, card deck, or magnetic tape.

- A post-processor listing.

c. Post-processor manuals shall be provided for all post-processors used for part preparations.

d. Should a separate part-program storage facility be proposed, the Supplier will furnish complete software source documentation. This shall be done in such a manner and detail that future modification may be conducted by the Purchaser without additional Supplier involvement.

e. "NC Downloading Subsystem Specification" on page 37 contains specifications pertaining to NC part programs.

5. Fixture Application for Part Processing

For each fixture provided, a cross-reference listing identifying the piece-part drawing number and specific machining operation(s) will be supplied.

A complete description of the fixture coding procedure recommended will also be included. This will include hardware and software necessary to provide a foolproof system of operation.

6. Setup Procedures

For each identifiable piece set up, a complete set of instructions, including sketches, if needed, will be provided.

7. System Operation

The Supplier will provide a written plan for operating the system. Among other things, this will include:

a. Recommended lot size(s) and sequence of processing to achieve monthly production rates.

b. Recommended number of operators required at full production, including the anticipated utilization of each.

c. Utilization of each item of equipment proposed.

d. Any other elements deemed essential to successful system operation.

8. Accceptance Checkout

Preliminary acceptance and final acceptance of instructions provided under this section will be done in conjunction with system testing per "System Process and Acceptance Test(s)" of this Proposal Request.

1.1.14 System Process and Acceptance Test(s)

1. Scope

The Supplier will be required to demonstrate by machining (parts) the capability of the total system to achieve all objectives as detailed in the Proposal Request.

For the purpose of this testing, the Buyer will supply four (4) sets piece-part castings to be used in Preshipment Checkout, and six (6) sets for Final Acceptance.

2. Preshipment Processing and Acceptance

As part of this proposal, the Supplier will provide a detailed plan describing his recommended sequence of checkout and delivery schedules.

This step-by-step check of separate hardware modules must assure that the intended "elements" of the hardware, software, and machining processes are verified before shipment authorization. The "elements" will consist of:

- Machine/control features.
- Fixtures.
- Part programs.
- Cutting tools.
- Material handling features.
- Machining data transfer and verification.
- Machine process time(s).
- Hardware and software interfaces.

Supplier to provide standard measurement equipment and labor to verify machining results. Requirements for special inspection equipment are to be detailed in the proposal.

Acceptance for shipment will be contingent upon the successful completion of the tests intended for each "element". All such tests will be witnessed and approved by the Buyer's representative(s). The shipment release will be authorized by the Buyer.

3. Final System Operational Tests

After successful completion of all preliminary checkout and testing as detailed in preceding paragraphs of this Proposal Request, the final acceptance at (the Buyer's plant) shall consist of verifying the system's conformance to specification and a demonstration of the system's ability to produce all parts to drawing requirements within the estimated machine process time(s). This runoff testing at (the Buyer's plant) may include up to six (6) sets of piece parts. The Buyer will provide all standard and special measurement equipment plus labor to verify machining results. Final acceptance will be accomplished by the Buyer.

1.1.15 Warranty

The Seller is to warrant to the Buyer that the system equipment and supporting hardware/software is free from defects in material, workmanship, and title and will meet the specifications as called out in the purchase agreement.

This warranty shall be for one (1) year from final acceptance at the Buyer's plant.

If the equipment delivered does not meet the warranty specified above assuming normal and proper use and maintenance, the Buyer shall notify the Seller and make the equipment available for correction at the Buyer's convenience. The Seller shall promptly correct any nonconforming defect at its expense by repairing or replacing any defective or damaged parts of the equipment.

Those items repaired/replaced shall be warranteed for an additional one (1) year from such a time that all defects are corrected.

In the event the Seller fails to make prompt correction as provided herein, the Buyer, in addition to all other remedies available to it under law, may make, or have made, such corrections as are necessary with the expense thereof charged to the Seller.

1.2 PERTINENT FMS ISSUES

(Information that the Buyer has acquired during the pre-RFP stage and feels may aid prospective vendors should be included in this section. The example comments which follow are typical of those which might be included for a low-volume, high-precision production situation. Note that they are preceded by a caveat to the effect that they are for "information only".)

The Buyer, in studying his production requirements and current technology, has developed certain insights that the Seller may find beneficial to consider while developing his system concepts. This information, which is listed below, does not represent in any way a bias of the Purchaser toward any one system configuration; it merely represents ideas which the Seller may wish to consider.

- It appears, from a detailed study of the work content of the piece parts, that only two NC machining centers would be required to achieve the required production rates if the fixtures were palletized.

- Some of the work content requires very-high-precision equipment. However, it appears as though less than half the work content falls into this category. Thus, perhaps one high-precision machining center, or a standard accuracy machining center customized with a special spindle, scales, etc., can be used in conjunction with a standard accuracy machining center.

- An arrangement of one standard NC machining center and one high-precision NC machining center allows for roughing operations to be performed on the standard machine and all high-accuracy work be performed on the precision machine; this approach minimizes the thermal and mechanical distortion possible when performing both roughing and finishing on the same machine, but greatly increases the material handling and scheduling complexity of each part.

- A configuration with two different machines, on the other hand, does not provide redundancy in the event one of the machines fails. Downtime is extremely expensive, especially when the failure of one machine causes the other machine to become idle. There certainly are benefits to having redundant (i.e., two of the same) machines. In addition, fixtures, pallets, and tooling should be compatible with all machines in any case to reduce problems caused by downtime.

- A configuration with two duplicate, high-precision machines reduces the system's susceptibility to failure as well as amount of material handling necessary for each subset of parts; however, high-precision machines are expensive, increasing the amortized cost per part as well as the initial investment.

- Large tool storage capacity, whether in the form of long chains or interchangeable drums, would reduce the need for dividing ship-set production into batches, reducing overall production time and set up cost.

- Environmental control, in the form of a temperature-controlled room and conditioned coolant as well as temperature-controlled and stabilized castings may be required in addition to high-precision machines to achieve the necessary workpiece accuracy.

- Window-frame type fixtures minimize the number of fixtures required, and the number of times the casting must be set up, and they reduce set-up realignment difficulties.

- Many material handling systems would appear to be viable, from manually moving the pallet/fixture/part combinations from machine to machine to fully automatic, unmanned material handling systems, such as robots, straight-line cart-on-rails, straight-line wire- or cable-guided cart, random wire-guided cart, two-way conveyor, loop conveyor, etc.

- Automatic inspection equipment of sufficient accuracy and reliability may be cost efficient, especially in an automatic, palletized FMS due to the savings in manpower and time during inspection. Interfacing the automatic inspection machine to the NC controls of the machining centers would be especially beneficial with respect to real-time compensation of most inaccuracies the machines would experience over time.

1.3 EQUIPMENT PROCUREMENT STANDARDS

1.3.1 General Specifications

1. The requirements defined in the Proposal Request are mandatory requirements. Deviation from any requirement shall be requested for the Seller and must be agreed to by the Buyer in writing.

2. The equipment will be painted with epoxy paint to match a color chip provided by the Buyer.

3. Ambient conditions, utilities, and facilities available in the Buyer's plant:

   a. The Seller's equipment design and construction shall operate under the Buyer's normal utility services as follows:

      - Electricity: ...

      - Air: ...

      - Natural gas: ...

      - Shop ambient temperature range: ...

      - Steam: ...

- Hydrogen: ...
- Nitrogen: ...

b. For equipment requiring utilities or ambient conditions different from those stated in paragraph 3(a) of "General Specifications" on page 29, the Seller shall individually identify and propose such conversion equipment.

- The Buyer reserves the right to obtain such conversion equipment from a source or sources other than the machine tool or process Seller. Such decision by the Buyer will be made prior to order placement and so stated in the Purchase Order.

c. Maximum height of crane hooks from floor, and maximum crane weight capacities shall be as follows:...

4. Lifting and Jacking Points

a. Heavy equipment parts to have lifting holes or lags which shall be so arranged that safe lifting and moving can be accomplished with normal material handling equipment and slings or chains.

b. All equipment requiring leveling shall, in addition to leveling devices for permanent installation, have jacking or leveling aids, for instance, hydraulic jacks during installation and leveling.

c. All lifting and jacking points shall be clearly identified on all appropriate equipment components.

5. Vibration Control

If any equipment, under normal operating conditions, could cause vibrations which may adversely effect other equipment in the adjacent area, the Seller shall design an appropriate foundation or supply the Buyer with shock absorbing devices, or both, which shall isolate such vibrations. Machines that are sensitive to normal floor vibrations shall be provided with adequate protection by the Seller.

6. Equipment Cooling

Equipment components (control cabinets, hydraulic units, etc.), which require cooling by fan or compressor cooling devices, shall have self-contained units.

An alternate cost utilizing chilled water coils shall also be provided.

7. Accessibility

The equipment, including all auxiliaries, components, interconnecting wiring, piping, ducts, belts, and chains shall be arranged so that filters, access panels, doors, lubrication points and fittings, and adjustment points are located for ease of maintenance and service.

Adjustments and service which fall into the category of normal operator functions shall be possible without special tools, removal of bolted down covers, or aid of maintenance personnel. Steam, air, water, and gas shutoff valves shall be supplied by the Seller and located for convenient accessibility from the operating level.

8. Proposed Requirements

a. The Seller shall reference each paragraph and subparagraph of the Proposal Request and indicate his compliance or exception. Where applicable, the Seller shall detail how his proposed equipment complies with the individual subparagraph requirements.

b. The Proposal Request does not define the design details or features of the equipment which may be standard or optional, therefore, the quotation shall fully describe the Seller's proposed equipment and shall provide the following information:

- Complete equipment specifications, special or optional features, machine drawings or photographs, proposed foundation requirements, a 1/4 inch = 1 foot outline plan template, and other data in enough depth to permit a full technical evaluation by the Buyer.

- The proposal shall contain a total price and itemized prices for the entire equipment required to meet this specification with exceptions noted per 8(a) above. This will include all interconnecting wiring, conduits, piping, power tracks, etc., between equipment components. It will also include start-up supplies such as hydraulic oils, lubrication oils, etc., needed for initial operation. The following shall be itemized; the Seller may identify others:

  1) Basic machine/equipment.

  2) Motors and controls if not Seller's standard.

  3) Accessories such as coolant systems, dust collectors, separate power sources, special cutting heads, rotary tables, etc.

  4) Items of tooling, specifically defined in the Proposal Request.

  5) Optional items proposed by Seller.

  6) Shipping cost, F.O.B. the Buyer's receiving deck.

  7) Guarantee, warranty, and Supplier service plans.

  8) The following maintenance features as applicable:

     a) Diagnostic routines.

     b) Short-life parts.

c) Recommended spare parts.

d) Support during installation and checkout.

e) Maintenance programs available.

A delivery plan in weeks after receipt of order. This plan to include enough detailed breakdown to enable the Buyer to identify long cycle and limiting items and planned Supplier action. A suitable chart (Gantt or CPM) will accompany the proposal.

Other information as defined by the Buyer.

9. Information Required from the Seller

During the procurement cycle, the Seller shall, at the time stated herein, supply to the Buyer the information specified in the following subparagraphs.

Partial or noncompliance by the Seller with the requirements listed herein may constitute incomplete contract fulfillment. Authorization to ship shall be held up for incomplete or missing documents required prior to the scheduled shipping date.

Note: Drawings to NMTBA standards will be no longer than twenty-two (22) inches by thirty-four (34) inches with seventeen (17) by twenty-two (22) preferred. All drawings of a given size should be securely bound together with a protective cover. All photographs and other data in manuals should be bound in standard eight and one-half by eleven (8 1/2 x 11) inch binders.

a. Special Tooling and Fixturing

- Preliminary drawings of tooling shall be submitted to the Buyer for his review. Approval of these drawings by the Buyer is approval of concept only. The Seller is fully responsible for correct dimensions and functional operation of tools.

- Fully detailed, reproducible drawings of tooling shall be provided to the Buyer as part of the total documentation package.

b. Not Later than Eight Weeks After Receipt of Order

- Revised information needed to finalize requirements for utilities, layout preparation, process planning, and installation.

c. Not Later than Ten Weeks After Receipt of Order

- Three (3) sets of certified prints and one (1) set of certified, reproducible masters of recommended foundation design (assuming 4,000 lb/ft^2 soil bearing capacity). These drawings should indicate centers of gravity; location of anchor bolts within ±0.25 in.; leveling wedges; vibration dampeners;qoutline of machine accessories, utilities, and coolant trenches.

- Piping, tubing, conduit, and wiring trough layout and specifications intended to be part of the foundation along with interconnection locations.
- Dimensioned machine outline drawings showing specific location, type, and quantity of utility connections.
- Identification of the total connected VA load to include voltage range requirements, starting characteristics, motor descriptions (horsepower, load current), and other information needed to select a suitable equipment power source.

d. Not Later than Thirteen Weeks Prior to Scheduled Shipping Date

- Shipping Information:

  (1) Method of shipment, for example, flat car, box car, low boy, van (note: trucking preferred).

  (2) Number, description, size, and approximate weights of major pieces and external identification markings.

  (3) Number of conveyances per item (1) in this list to cover total shipment.

- Photographs or other pictorial description of the equipment to supplement and update previously received layouts and installation information.
- Installation, checkout, and start-up information:

  Rigging instructions, including schematic drawings identifying jacking and lifting points and, if possible, photographs showing lifts. Instructions should also identify lifting accessories such as slings, spreader bars, etc. Limitations of crane lifting weight and height under crane during installation should be identified.

  Setup and operating instructions including three (3) sets of operator and programming manuals. Also necessary is a list of tools, gauges, and equipment needed for this work.

  Note: Programming manual is defined as the procedures and programming format necessary for utilization of the total equipment package specified.

  Special precautions to be taken during installation of equipment. List hazards and potential hazards and recommended avoidance procedures.

Recommended spare parts list by manufacturer's name and identification number, procurement cycle, and the cost of each item. This should include, but not be limited to:

Types of filter
Lubrication systems
Hydraulic hose fittings
Hydraulic pumps and valves
Electrical components
Other standard parts specified

After reviewing this listing, the Buyer may order directly or procure via the Seller, those parts he determines necessary. Parts procured from the Seller must be delivered with the equipment.

e. Not Later than Eight Weeks Prior to Scheduled Shipping Date

Two (2) complete sets of the following prints shall be furnished for review by the Buyer:

Note: All electrical drawings shall show ground runs and connecting points. Wiring will be color coded for ease of maintenance and safety. Changes to documentation will be on the original sheet if possible. Modifications or changes shown on new drawings, etc., must be cross-referenced to the original sheet and vice versa.

- Electrical elementary diagram, which includes identification of switches, fuses, and circuit breakers by type and sizes.

- Electrical interconnection diagram.

- Electrical wiring diagram showing panel layout and location of all electrical components with respect to the basic machine. The Buyer reserves the right to specify dimensions and locations for remotely located cabinets, control panel, etc.

- Internal wiring of individual devices if not shown on wiring diagram.

- Any electronic, hydraulic, or pneumatic diagrams similar to the electrical diagrams described above.

- Machine assembly drawings required for erection, installation, and maintenance of the machine tool. Drawings will include critical dimensions such as clearances, slide motions, extensions during erection, size of auxiliary cabinets and hydraulic units, and the relative dimensions of major components to each other.

- Drawings of assembly and details with dimensions for components of the machine tool which are expected to have relatively short life.

- Four (4) copies of the following shall also be furnished:

  Maintenance instructions and Parts Manuals.

  Lubrication information (type, location, quantity, based on Mobil Company standards).

  Cleaning instructions (related to uncrating and installation).

  Installation and start-up procedure.

  Recommended preventative maintenance schedules.

f. Supplied with Shipment

One (1) set of marked up prints delivered under separate cover, as needed to reflect configuration of equipment completing preliminary acceptance.

g. Not Later that Three Weeks After Acceptance at the Buyer's Plant

- One (1) complete set of certified reproducibles of the drawings specified in points 1, 2, 3, 4, and 5 of paragraph (e) above.

10. Health and Safety Provisions

a. The Seller shall guarantee that the equipment meets or surpasses the safety provisions of the Federal Walsh-Healy Law.

b. The Seller shall guarantee that the equipment meets or exceeds all provisions of the Williams-Steiger Occupational Safety and Health Act of 1970 and any regulations issued thereafter that apply to this equipment and its operation.

Note: Exception to subparagraph 10(b):

Noise control engineering practices to be applied to keep sound levels at the lowest possible limits. The maximum allowable noise level of machine, the cutting tools or a combination or both shall not exceed 83 dBa measured within four (4) feet of any noise source.

11. Patent Indemnity

The equipment Seller shall protect and hold harmless the Buyer against any and all demands and claims, on account of infringement or alleged infringements of patented, or alleged patented articles or inventions, used on or for this equipment, and will, at his own cost and expense, defend any and all suits which may be brought against the Buyer or Seller on account of infringement, or alleged infringement, and pay all cost fees and damages resulting thereform.

12. Proprietary Data/Information

In the event the equipment specification contains information which is proprietary to the Buyer, the specification will be marked "PROPRIETARY" and will be provided upon the express conditions that:

- It will be used only for the purpose intended.
- It will be returned when the intended purpose is completed.
- The Seller will maintain the information in confidence during the time it is in Seller's possession. The Seller, however, shall not be held responsible for disclosure or use of information which becomes part of the public domain as a result of the acts of others, or for an inadvertent breach of confidence despite the Seller's application of reasonable care to preclude unauthorized disclosure.

13. Offshore Manufactured Equipment Requirements

a. The word offshore as used here shall be defined as being outside the continental limits of the United States of America, Hawaii, or Alaska. Offshore manufactured equipment is equipment manufactured in whole or in part outside the continental limits as defined above.

b. All threaded fasteners shall be Unified Thread Series UNC or DNF as defined by American Standards Association Standard ASA B1.1 1949.

c. All nameplate nomenclature shall be in the Americanized form of English. Control nameplates which utilize sign conventions to identify the control functions shall, in addition to the sign conventions, have engraved nameplates verbally describing the control functions.

d. All drawings have the notes both in the language of origin and in the Americanized form of English. Where dimensions are shown in metric units, the English system (inch) equivalent will also be shown. Hydraulic, pneumatic, and electrical symbols shall be per NMTBA standards.

e. All instruction manuals and parts lists shall be translated into the Americanized form of English (i.e., a wrench shall be called a wrench and not a spanner, or an electron tube shall be called an electron tube and not a valve). Torques or other force forms shall be called out in English units.

f. Equipment inspection at the Seller's plant shall utilize Seller-supplied measurement tools whose calibration is in English units, and whose calibration is directly traceable to the National Bureau of Standards. The language to be used during the equipment inspection will be the Americanzed version of English. Therefore, if necessary, the Seller shall have available a capable translator.

g. All dimensional readout equipment supplied with the purchased equipment shall read directly in inch units. The use of conversion factors which require separate calculation will not be allowed.

h. Sellers proposing to sell offshore manufactured equipment shall in their proposals specifically reference this paragraph (13) and each item thereunder specifying their conformance thereto.

1.4 NC DOWNLOADING SUBSYSTEM SPECIFICATION

1.4.1 System Operation

The NC machining system shall have hardware/software capabilities for part program storage and automatic part program call-up and execution as follows:

1. Each pallet/fixture shall carry coding which will identify the piece part and machining operation called for. Where fixtures are used for more than one attitude or for more than one piece part, this code must identify the active part/attitude. This pallet/fixture code shall automatically be read and shall cause the appropriate part program to be downloaded to the NC controller for execution.

2. The system (NC machines and controllers, pallets/fixtures, coding devices, computer, and all associated hardware and software) shall be designed such that no machining operation can be automatically accomplished out of the proper sequence (e.g., a program for Drawing XXXXX; Operation 2 shall not be activated until Operation 1 has been executed).

3. Recognition of the pallet/fixture identification code shall not cause the part program to be downloaded if the requested program is currently resident in the NC controller. Before a program is downloaded, any program resident in the control must be cleared from memory.

4. The system shall be capable of checking for transmission errors during the downloading of programs. If errors are encountered, automatic retransmission shall occur until an error-free transmission is realized. If successful transmission is not possible after ten (10) attempts, this condition shall be so noted on the NC controller's message display, the central computer facility, and on the master control panel located in the machining area. In addition, there shall be an audible signal to alert the operator of a transmission problem.

5. In the automatic mode, the pallet/fixture recognition, the downloading of the appropriate part program, and the execution of this program shall require no operator intervention.

6. The system shall also allow a request for downloading to be manually initiated from a remote operator station.

7. The system shall have the capability for editing part programs at both the central computer facility and the NC controller. Programs edited at the NC controller shall be able to be uploaded to the central computer.

8. If any machine is out of service, the system shall be able to be reconfigured so that part programs normally allocated to that machine shall be able to be allocated to an alternate machine utilizing existing pallet coding.

9. The system shall be capable of handling simultaneous program editing/maintenance and normal systems operation in a multitasking environment.

10. Random tool table, tool offset table, and fixture offset table shall be able to be loaded into NC controller by punched paper tape or downloaded from central computer.

1.4.2 Central Computer Facility

The central computer facility shall be used for bulk program storage, downloading programs and program maintenance and shall be capable of the following:

1. It shall have sufficient nonvolatile storage to simultaneously store all part programs, executive programs, and maintenance programs.

2. The central computer will be connected to the CNC controllers with dedicated communication lines. It shall be capable of error-free part-program transmissions at a rate of no less than 2400 baud.

3. Hardware for the central computer facility shall be supplied by (the desired vendor) and shall include the following: ...

4. The system shall have a remote video terminal located in the machine area.

5. The central computer should be capable of multiplexing (interleaving data transmissions) of part programs to all CNC controllers.

1.4.3 Software/Documentation/Training

1. Custom software shall be provided in source and object form. Source programs shall be adequately commented. A Programmer's Manual shall

be provided containing sufficient information to allow a programmer to correct, modify, or add new features to the software. The following items shall be included:

- Detailed flowcharts or PDL (Program Description Language) descriptions of each task in the system. Each flowchart or PDL description must include every branch of logic in the program.

- Data structure details. In FORTRAN, this means an explanation of how data existing in arrays is referenced through subscripts. Also included in this requirement is a description of data record formats in disk files.

- Data input/output details including information on which routines and tasks handle I/O, what I/O they perform, and any encoding/decoding performed.

- Task inter-relationship details explaining how tasks communicate with one another, how event flags are used, and how the resident common area is used. This information is critical because the multitask nature of the download system could have timing problems in updating variables in common, for example.

- A section on installation notes is also a requirement because a programmer will be required to reinstall and download software following every installation of a new release of the operating system. Such things as what system options to select, how to partition memory, etc., are an important consideration during system generation.

- Functional description of each subsystem providing an overview in flowchart form of how data passes in or out of the subsystem. In addition, the flow of operations within each subsystem shall also be outlined.

- Descriptions of all arguments and variables in each subroutine, main program, or common, including a functional definition of how the variable is used.

- The Buyer shall review and approve all documentation formats/structure.

- The Buyer shall review and approve all final documentation prior to acceptance of download system.

2. Command files for task building shall be provided.

3. All programs shall be written in either FORTRAN or Assembly Language with FORTRAN being used whenever possible.

4. A (desired) operating system shall be provided.

5. All documentation and diagnostic programs that are received by the vendor with the computer hardware/software shall be provided to the Buyer.

6. A diagnostic program to verify the communications lines are working shall be provided.

7. Comprehensive User's Manuals shall be provided detailing the system's operation and shall include a user's diagnostic section explaining how to diagnose problems. For diagnosing problems, the guide must present each possible error symptom and what steps to take to diagnose the error cause, fix it, and verify that it has been fixed.

8. Sufficient training shall be provided to appropriate Buyer personnel in systems software and operation.

9. Custom software shall be backed up at periodic intervals during the software development phase.

1.4.4 Future Expansion Capabilities

The software/hardware shall be capable of handling expansion/upgrading as follows:

1. System shall be capable of ultimately multiplexing (number of) CNC machines.

2. Systems have capabilities for upgrading to allow the monitoring and maintaining of data on the activities of the individual NC machines as follows:

   a. System shall be capable of providing status reports on system activities upon request. These reports shall include an identification of the current part and pallet/fixture resident at each machine, the current operation being performed, the percentage of completion for each operation and completion status on all parts in system.

   b. System shall be capable of providing machine utilization reports which shall include uptime/downtime, reason for downtime, amount of wait time and reason, and percentage of time machining versus total time available for each individual machine.

   c. System shall be capable of providing tool reports which shall include estimated tool life, actual use, and tool mortality for all tools in the system. When tool wearout time occurs, the operator shall be notified on the master control panel.

   d. System shall be capable of providing production reports which shall include completions, completion schedules, progress on schedules, and status of parts in system.

1.4.5 Milestone Charts/Progress Reports

1. The Buyer shall have approval responsibility for system design.
2. When accord has been reached on system design, the Buyer shall be provided with task statements, action plans and milestone charts.
3. The Buyer shall be provided with sufficient reports on progress toward completion of milestones.
4. The vendor will provide the Buyer with a detailed software specification and test plan.

1.4.6 Operational Test and Acceptance

The operational test and acceptance of the downloading subsystem shall be in conjunction with the system operational test and acceptance procedure.

1.5 MACHINE ACCEPTANCE TEST SPECIFICATIONS AND PROCEDURES

(Include company specific test specifications, procedures, machining tests, machining test drawings, etc., in this section.)

2.0 EXAMPLE PROPOSAL FOR AN FMS TO MACHINE PRISMATIC PARTS

A copy of a detailed proposal and quote for a six-machine FMS to produce a set of prismatic parts is shown on the following pages. The names of the customer and the vendor have been changed.

2.1 PROPOSAL LETTER OF TRANSMITTAL

March 16, 1981

Attention: Purchasing Department
XYZ Manufacturing Corporation

Subject: Flexible Manufacturing System
Your RFQ No, 475 and File No. CAST 10-1
Our Proposal Number A-430-8999-R1

Gentlemen:

We are pleased to present this proposal for a Flexible Manufacturing System to produce retainers, covers, housings, and towers.

Please refer to our Proposal Drawing A-430-8999-R1 for the floor plan arrangement of the machines and equipment by this proposal.

This proposal was designed to meet the following objectives and parameters.

1. Objectives:

   a. Minimize direct labor.

   b. Reduce lot sizes.

   c. Provide flexibility.

   d. Minimize cost to accommodate engineering changes.

   e. Minimize investment and operating costs.

2. Parameters:

   a. This proposal will cover the machine and equipment required to produce your production requirements of the following parts:

Part No.	Description	(Daily)
1246-301-032	Bell Cover	101
1246-301-035	P.T.O. Cover	15
1246-301-037	Main Housing	15
1290-301-065	Bell Cover	168
1290-302-101	Bearing Retainers	84
1290-302-072	Bearing Retainer	84
1246-302-110	Bearing Retainer	101
1246-306-068	Shift Tower	161
1290-307-001	Control Housing	108

b. Available time is twenty-four hours per day at 65% efficiency.

c. Available space, 40-foot-wide bays with columns on 60-foot centers, was used to construct the system layout. Approximately four bays will be required.

The following is a very general description of the equipment which we are offering; for more detail, please refer to the attachments of this letter.

To accomplish the objectives and stay within the parameters, we are proposing a flexible manufacturing system consisting of the following machines, equipment, and services:

1. Six Model 007 Machining Centers as described in Publication No. M-5233-1, including the following:

   - X = 44, Y = 36, Z = 28 travels.
   - 30-tool matrix.
   - 32-inch square index table with 360 positions.
   - Pallet delivery/discharge units with pallet queue areas.

2. One automatic material handling system consisting of the following:

   - Necessary wire-guided transport carriers.
   - Installation of wire-guide path and controllers.
   - Control system.
   - Interfacing to FMS central control computer.
   - Software covering six machines and six load/unload stations in the staging area.

3. Six manually-operated load/unload stations in the staging area and three loader consoles complete with CRTs and keyboards interfaced with the FMS computer.

4. One load/unload station for the storage of pallet/fixture combination. No method of communication with the FMS computer is required or supplied at this station.

5. FMS computer control system including all necessary hardware and software.

6. Air-conditioned room for FMS computer.

7. Necessary pallets.

8. Necessary fixtures.

9. Necessary NC programs.

10. Supervision of installation and on-site project management.

11. Service and warranty for one year, not to exceed eighteen months from date of shipment.

12. Documentation of machines and system.

13. Training of your personnel.

Equipment Runoff and Installation

In order to expedite delivery, the machines will be runoff at our plant in the stand-alone configuration. We are proposing that three different parts be run on each of the first three machines. A simulated production run of ten parts of each type would be made as described above. This would serve as a preliminary verification of the cycle time and quality capability of the equipment. These machines would then be shipped and married to the material handling system at your plant.

The three additional machines would be demonstrated with standard test cuts only prior to being shipped. By using this approach, the entire system can be shipped in approximately 82 weeks from the placement of an order.

Quotation

For the pricing and delivery schedule of the above-mentioned equipment, plus an approximate price for durable and perishable tooling and programming, please see the attached "Pricing, Deliveries, Terms, and Conditions".

Thank you for the privilege of quoting on your system requirements. If you have any questions regarding this proposal, please do not hesitate to contact us.

Very truly yours,

(Signed)

Sales Project Engineer

(Signed)

Field Engineer

In Triplicate Enclosure

2.2 SYSTEM DESCRIPTION

2.2.1 Equipment Description

1. Six Model 007 Machining Centers with Computer Numerical Control (CNC) complete with 32-inch square, 360-position index table, and delivery/discharge units. (Please see below for a detailed descrption.)

2. Six manually-operating load/unload stations with necessary equipment for communication with the computer. Note: Two load stations will be serviced by one CRT and keyboard.

3. One automatic material handling system including three electric wire-guided transport carts, software covering six machines, and six load/unload stations. It also includes installation of the wire-guide path and controllers.

4. Battery-charging equipment for transport carts.

5. Twenty-one pallets - 32 inches square.

6. Twenty-one fixtures; we estimate the distribution to be as follows:

Part Name	Amount
Retainer 101 and 072	2
Retainer 110	1
Cover 035	1
Housing 001	4
Tower 068	4
Bell Cover 032	3
Bell Cover 065	5
Housing Main 037	1

7. Six sets of durable tooling and six sets of perishable tooling for machining the part numbers listed in item (6) above. (One set of durable and one set of perishable tools per machine.)

8. NC programs to produce the parts listed in item (6).

9. Part runoff at our facility.

10. Supervision of installation at your facility.

11. Service and warranty for one year, not to exceed eighteen months from the date of shipment. Warranty date to be established for each separate phase of installation.

2.2.2 Machine Description and Part Flow

There will be six Model 007 Machining Centers in the system.

These traveling column machines have 44 inches of "X" axis travel, 36 inches of "Y" axis travel, and 28 inches of "Z" axis travel. Also included is a 30-tool chain matrix, 32-inch-square pallets, 360-position index table, 20-horsepower spindle drive, and shuttle mechanisms (delivery/discharge) for the automatic material handling of the palletized workpieces. The shuttle mechanism is a through-type shuttle and is located on each side of the work table. (See below for detailed description.)

The machining centers will be tooled to perform the miscellaneous machining operations on the various transmission parts.

There will be six manually-operated load stations and three CRTs and keyboards for communications with the computer.

There will be one additional load station for pallet storage. No equipment will be supplied on this station for communication with the computer.

One automatic material handling system, including three electric wire-guided transport carts, software covering six machines, and six load/unload stations. It also includes installation of the wire-guided path and controllers. (Refer to the Material Handling System, below for more information.)

The machines, load/unload stations, and material handling system are under direction of the FMS computer control system. (See Sections 2.2.4 through 2.2.14 for more information.)

A total of twenty-one pallets with fixtures is included in this phase of the system.

2.2.3 Operating Philosophy

The following is a description of the basic technique used in operating the proposed FMS.

2.2.4 Production Planning

The production requirements are determined by the customer's internal production control department. These requirements are passed onto the FMS manager (department foreman), and he plans the production within the FMS to meet those needs.

The workpieces to be machined in the system are previously defined at the FMS control center. This includes:

1. Defining the relationships between workpieces, fixtures, and pallet.

2. Identifying the priority of each workpiece.

3. Defining the routing of each of the workpieces.

2.2.5 Routing Assignments

Predefined routings will be loaded into the computer, and these routings will be used to guide the part to the various machining and load/unload stations during its manufacture while in the system.

2.2.6 Modularity

The system is built in modular form for ease of future expansion.

2.2.7 Operating Policy

1. Parts are introduced to the system in batches made up of a mix of parts meeting production goals. The parts are placed in waiting queues that are dedicated to certain fixture/pallet types. The pallet types are, in turn, bound to a unique load/unload station.

2. When a pallet returns to its unique load/unload station, its part is unloaded.

3. The loader selects an appropriate part from one of the waiting queues and loads it on the pallet. The loader then informs the control system which part, setup, and fixture is ready for dispatching.

4. The control system consults an ordered listing of processing steps for the given part and selects an appropriate station for the first processing step. If there is a choice of stations, the best one is selected. The transport system is then directed to move the part to the selected station following an optimum pathway as determined by the control system.

5. When the part reaches the selected destination, it may wait until the station is free and then the part will be transferred onto the station and the processing cycle will be initiated.

6. When processing has been completed, the control system again consults the list of processing steps to find where the next step is to be per-

formed. Items (4), (5) and (6) of this list of events are repeated until all processing on the list has been completed.

7. As the last processing setup, the completed part is sent to its unique load/unload station for removal from the fixture/pallet. At this point, the fixture/pallet is reloaded from an appropriate queue and sent back to the system. If no raw part is available, the fixture must be removed from the system. The returning part may be totally finished or may be placed in a queue of parts waiting to enter the system for additional processing in another fixture. In the latter case, steps (1) through (7) of this list of events will be repeated, with a new list of processing steps.

The series of events just described will be simultaneously taking place for a number of parts. Each different kind of part will be processed somewhat randomly, under the direction of the control system, which is using built-in algorithms to meet defined objectives. Objectives may include the meeting of production goals and/or the maximizing of work station utilization. Human interaction is required for such things as correction of malfunctions, monitoring and replacement of tooling, and defining of production requirements.

2.2.8 Production Parameters and Assumptions

The purpose of the system is to manufacture transmission case parts.

2.2.9 Production Requirements

Part No.	Description	Amount (Daily)
1246-301-032	Bell Cover	101
1246-301-035	P.T.O. Cover	15
1246-301-037	Main Housing	15
1290-301-065	Bell Cover	168
1290-302-101	Bearing Retainer	84
1290-302-072	Bearing Retainer	84
1246-307-110	Bearing Retainer	101
1246-306-068	Shift Tower	161
1290-307-001	Control Housing	108

2.2.10 Time

Available time is twenty-four hours per day at 65% efficiency.

2.2.11 Assumptions

System production is based on the following assumptions:

1. The following parts are to be cast iron (200 BHN) and machined per the dated part prints.

Part Name	Part Number	Dated	Print Name
Retainer	1290-302-101	9-15-80	(Connection Plate)
Retainer	1290-302-072	9-15-80	(Connection Plate)
Retainer	1246-307-110	9-12-80	(Connection Plate)
Cover	1246-301-035	9-12-80	--
Housing	1290-307-001	8-12-80	(Gear Change Cover)
Tower	1246-301-068	8-12-80	(Gear Change Cover)
Bell Cover	1246-301-032	9-12-80	(Bell Housing)
Bell Cover	1246-301-065	9-15-80	(Housing Clutch)
Main Housing	1246-301-037	8-12-80	(Housing)

2. Part Numbers 1290-302-101, 1290-302-072, and 1246-307-110 are to be roughed out off-line before being introduced into the FMS.

3. Various parts will run through the system simultaneously.

4. System operators will notify the computer system of the part number which has been loaded into the fixture. After the part has been dispatched into the system, the computer will control the flow of the part.

5. As the load station is manually operated, production is dependent on the availability of a load operator and workpieces.

6. Parts (workpieces) are to have cast qualified fixture location points and are to be free from flash and inclusions.

2.2.12 Part Tolerances

Part tolerances will be as outlined in the dated Part Drawings listed under "Assumptions" above.

2.2.13 Personnel Requirements

The following direct and indirect labor would be the minimum requirement:

Direct

(3)	Part loaders and unloaders
(1)	Utility Main
(1)	Tool Maintenance Man

5	Men per shift

Indirect

(1/2)	Mechanical Maintenance
(1/2)	Electrical Maintenance
(1)	System Manager (Foreman)

2	Men First Shift
1	Man Other Shifts (System Manager)

2.2.14 Part Programming, Fixtures, and Tooling

The FMS vendor will supply the NC tapes, fixtures, and tooling to machine the parts listed in this proposal.

2.2.15 Peripheral Equipment (Supplied by Customer)

1. Wash equipment at each load station.

2. Light crane at each load station.

3. Equipment to supply rough parts and remove finished parts from the load stations.

4. Storage racks for idle fixtures and pallets.

5. Tool carts for handling of durable and perishable tools while servicing tools.

6. Necessary equipment for setting and servicing tools.

2.2.16 System Layout

See Figure 1 on page 54.

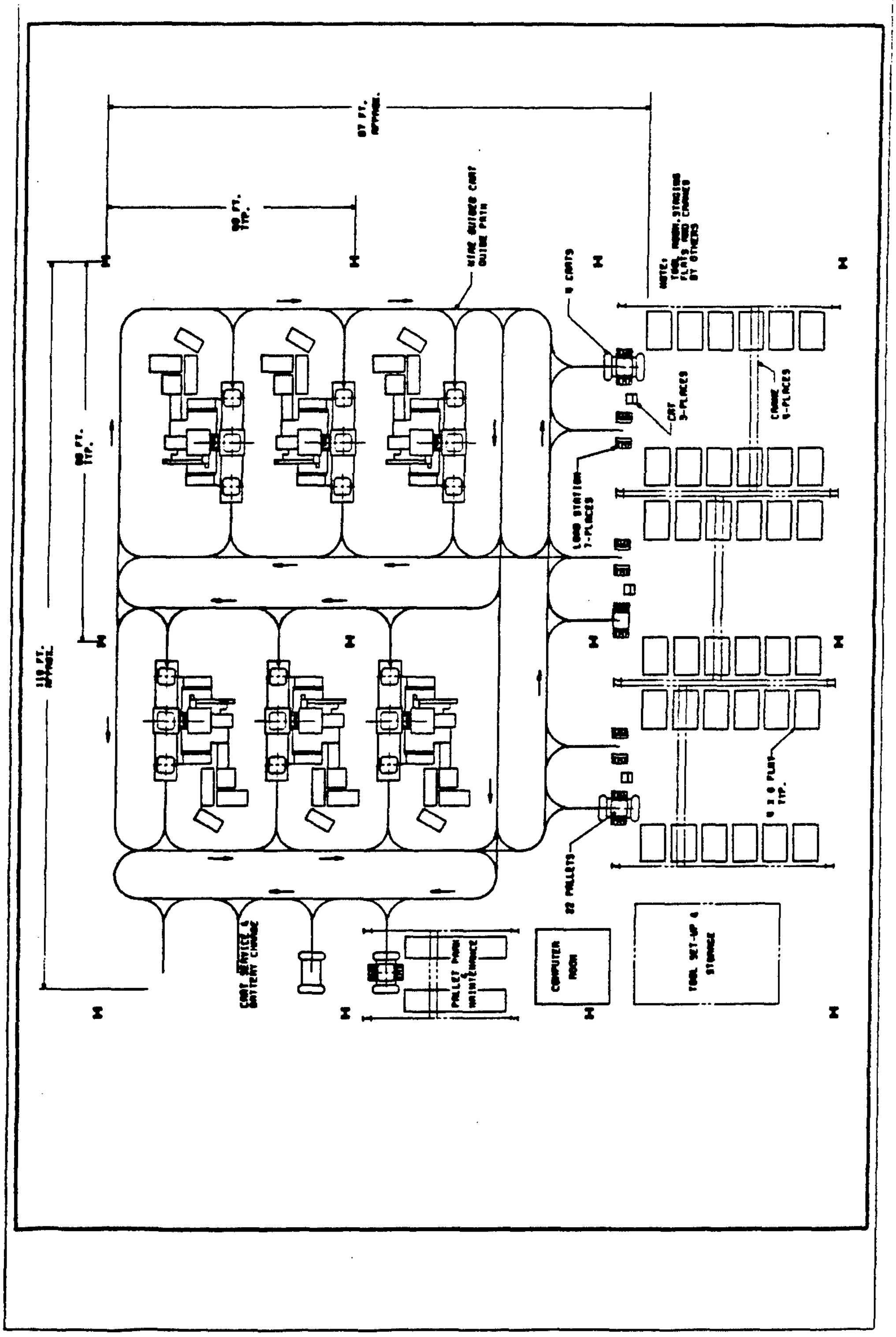

Figure 1. Layout of FMS for Proposal A-430-8999-R1

2.3 MACHINE DESCRIPTIONS

2.3.1 Model 007 Traveling Column NC Machining Center Features

1. Efficient Automatic Tool-Change Mechanism

   a. The tool-change mechanism accepts V-Flange No. 50 taper tool holders.

   b. Tools are interchanged automatically in four seconds by means of a double arm.

   c. Tool selection is random, with the tool being positioned for interchange during the machining cycle. There is no loss in production time.

2. Twenty-Horsepower Spindle Carrier

   a. A rugged 20-horsepower (15 kw), continuous duty spindle carrier, front-mounted on a rigid column has been incorporated into the machine design.

   b. The No. 50 taper spindle, single-key drive, is extended 8 inches (200 millimeters) from the face of the carrier.

   c. The spindle is automatically oriented (mechanically) at each tool change.

   d. Automatic air flow through the spindle at each tool-change cycle is included to reduce the possibility of contamination of the taper.

   e. The spindle carrier has a torque rating of 0.20 horsepower/rpm.

3. Stationary Work Module and Delivery Discharge

   A fabricated steel module, floor-mounted, will be coupled to the machine. A 360-degree indexing mechanism, which is eqiupped with a pallet reciever, will be part of this module.

   The front module will be equipped with a fabricated steel delivery/discharge system which will accept pallets/fixtures from the carts and automatically make the transfer into and out of the work module.

4. DC Electric Servos

   DC servo motor drives with SCR amplifiers are included for X, Y, and Z axes. Z-axis drive has a 5,000-pound (2280 kgf), continuous duty thrust rating and 8,000-pound intermittent duty rating. A DC servo motor also drives the index table.

Note: Maximum Z-axis thrust above 24 inches (600 millimeters) is 4,000 pounds (1850 kgf) at the center of the table, reducing to 3,000 pounds (1358 kgf) above this height and 15 inches (380 millimeters) from the center of the table.

5. Linear Scale Slide Feedback

   The X, Y, and Z axes are equipped with linear-scale feedback devices to provide accurate slide positioning.

6. Precision Electronic Probe (Extra Cost Option)

   This feature consists of a precision electronic probe connected to dedicated software in the NC control. Through simple programming of certain parameters, the probe will automatically perform the following:

   > Test for presence of part or surface, detect incomplete machining operations, perform in-process inspection, locate part program setup to align machine, detect stock variations or core shifts in rough castings, or align machine to previously machined surfaces.

   The probe unit will be mounted in a special No. 50 NMTB "V" flange holder and on command will be automatically loaded into the spindle from the tool storage drum.

7. Model 007 Computer Numerical Control Unit

   This unit incorporates the latest in NC technology, providing full three-axis positioning and contouring capability, plus plane selectable circular interpolation. This control includes:

   a. Absolute or incremental dimensional input resolutions of 0.0001 inch (0.001 millimeter).

   b. Cathode ray tube (CRT) display.

      - Command position readout.
      - Sequence number readout.
      - Tool number.
      - Spindle speed.
      - Operator messages.
      - Feed rate.
      - System fault conditions.

- G-80 codes.

c. Alphanumeric keyboard provides for manual data input of all tape data.

d. Three-axis linear-plane-selectable circular interpolation and helical interpolation.

e. Absolute/incremental switchable input by G-code.

f. Buffer storage of 400 characters.

g. ± programming for X, Y, and Z axes.

h. Programmable feed-rate lockout permits program lockout of the feed-rate override feature by programmed M-codes.

i. Fixed cycles for drill, tap, and bore, including dwell and automatic acceleration and deceleration in positioning mode, G-80 Series.

j. Inch/metric switchable.

k. EIA RS-244/EIA RS-358 switchable tape coding format.

l. Programmed dwell (0.01 second increments up to 99.99 seconds).

m. Block delete.

n. Grid align; target point align.

o. 300 lps photoelectric tape reader, including 7-1/2 inch (190 millimeters) reels.

p. Tape search; forward or reverse.

q. Air conditioner for CNC console.

r. Function lock inhibits:

   - Edit.
   - Edit buffer inhibits.
   - Edit buffer clear.

s. Edit - provides sufficient memory for storing 1,000 characters of NC data corrections.

t. Tool length storage - provides 0.0001 inch (0.001 millimeter) to 99.9999 inches (999.999 millimeters) tool length storage/compensation for each pocket.

u. Tool usage monitor - automatically computes time in minutes (up to 3276) that a tool is actually cutting, as compared to its predicted effective tool life.

v. Assignable tool length trim - used to compensate for setup variations. Provides sixteen tool trims with range of ±0.0001 inch (±0.001 millimeter) to ±1.000 inch (±25.0 millimeters).

w. Cutter diameter compensation - provides ±1.000 inch (±25.0 millimeters) of compensation on diameter. (One for each tool pocket.)

x. Sixteen fixture offset groups - a feature providing automatic compensation for fixture or workpiece misalignment relative to table centerline or to other workpieces. Each X, Y, Z offset group has a range of ±99.9999 inches (±999.999 millimeters). Offset value is entered into the system by the operator.

y. Alphanumeric keyboard cover with lock.

z. Machine/Mechanism Diagnostics.

<u>Note:</u> With this feature, an alert code is displayed on the CRT as soon as a mechanism fails to operate properly. The displayed alert code provides an instant reference to the diagnostics manual, which is part of this package. Thus, the customer becomes self-sufficient in both detecting and correcting machine mechanism problems.

8. Machine Specifications

<u>Range</u>

Longitudinal (X) travel	44" (1100 mm)
Vertical (Y) travel	36" (3" to 39") 910 mm (75 mm to 990 mm)
Cross (Z) travel	28" (6" to 34") 710 mm (150 mm to 860 mm)

<u>Index Table</u>

Rotary index table	32" x 32" square (800 mm x 800 mm)
Number of index positions	360
Increment of index	1 degree
Index table T-bolt slots (number and size)	6 - 11/16" (17.4 mm)
Precision keyways at 90°	0.8125/0.8135 (20.621 mm/20.647 mm)
Indexable workload	5000 lbs (2280 kg)

<u>Spindle Carrier</u>

Spindle nose	V-flange No. 50 taper
Spindle nose extension	9.5" (240 mm) diameter x 8" (200 mm) extension
Spindle drive motor	20 hp (15 kw) DC

	(Continuous duty rated)
Spindle speed range	20 to 3300 rpm
	(20 to 400 rpm optional)
Spindle speed increment	Each rpm
Torque capability	0.20 hp/rpm

<u>Feed Range</u>

Longitudinal (X) axis	0.2 to 150 ipm
	(5 to 3810 mmpm)
Vertical (Y) axis	0.2 to 150 ipm
	(5 to 3810 mmpm)
Cross (Z) axis	0.2 to 150 ipm
	(5 to 3810 mmpm)
Rapid traverse	400 ipm (10,000 mmpm)

<u>Automatic Tool Changer</u>

Tool holder	V-flange No. 50 taper
Maximum tool weight	50 lbs (23 kg)
Maximum moment around grip point	400 inch pounds

<u>Tool Storage</u>

Capacity	30 tools
	(60 tools optional)
Maximum tool diameter - full chain	4" (100 mm)
Maximum tool diameter - adjacent pockets empty	10.5" (265 mm)
Maximum tool length	17" (430 mm)

Maximum unbalance:
condition should not exceed 200 lb (90 kg).

<u>Utility Requirements</u>

a. Electric (Index Only) 100K VA
Electric (Contouring Only) 120K VA

b. Air - 20 cfm @ 60 psi minimum - 100 psi maximum.

c. Water - 450 gallons/hour @ 80°F. (Not required when refrigerant-coolant heat exchanger option is supplied.)
changer option is supplied.)

d. Ambient temperature - 60°F minimum, 120°F maximum.

<u>Machine Weight and Floor Space</u>

Net weight (approximately) 43,000 lb (19,500 kg).

Overall floor space (approximately) with optional chip conveyor - 26' wide x 18' deep.

Overall height from floor 147" (3734 mm).

9. Positioning and Alignments

The following inspection and tests will be made in our plant prior to machining customer workpieces. These are internal tests and will not be demonstrated as part of the machine acceptance.

The result will be recorded and will be available on request.

Please see below for the construction of the machine acceptance.

10. Positioning Accuracy

All positioning accuracies quoted apply when the machine has reached the recommended operating temperature. Furthermore, these tolerances only apply when the linear position movements are in the same direction (unidirectional) and are parallel to the slide axes. All points are measured from the theoretically perfect target zero with the zero position having the same tolerance or dispersion as any other slide position.

Based on the above parameters, the positioning accuracies are as follows:

a. The unidirectional slide positioning accuracy for Y and Z linear axes is ±0.0005 inch (±0.0126 millimeter).

b. The unidirectional slide positioning accuracy for X linear axis is ±0.0007 inch (±0.0175 millimeter).

c. The unidirectional repeatability accuracy for each linear axis is ±0.0002 inch (±0.005 millimeter). This repeatablity is within the positioning accuracy tolerance limits noted above.

d. The rotary index table positioning accuracy is ±5 seconds of arc, nonaccumulative.

2.3.1.1 Chip Conveyors (Extra Cost Option)

The chip conveyor and chip elevators can be provided with each machine at extra cost.

2.3.2 Other Equipment Required for System Operation

2.3.2.1 Load/Unload Stations

The load/unload stations will be heavy steel fabrications and will be arranged to accept one 32-inch-square pallet at a time from the carts.

Each load/unload station will have pallet readers and will contain the necessary equipment for the operator to communicate with the computer.

<u>Note:</u> In this proposal, two load stations will share one CRT and keyboard (i.e., six load stations, three CRTs and keyboards).

2.3.2.2 Fixtures

The fixtures will be steel fabrications with hardened and ground locating details. All fixtures will be manually clamped and will have quick-action clamps wherever possible.

Final configuration will be defined after completion of fixture layouts and approval by your tooling personnel.

2.3.2.3 Tooling: Durable and Perishable

The following tool list is tentative and based on the tooling we have selected. Final configuration will be after tool layouts have been made and approved by your tooling personnel.

<u>Part No. 1246-306-0684 (Drawing No. 1246-306-069)</u>

1. Shell End Mill 5.0" diameter 10 Tungsten Carbide (T.C.) blades.

2. Drill 9 mm (0.354") T.C. standard Flute Length (F.L.)

3. Spot drill 0.50 diameter High Speed Steel (H.S.S.)

4. Drill 0.197" diameter T.C.

5. Hollow mill and chamfer tool diameter 90 mm 2 T.C. blades, 2 T.C. chamfer blades 30°.

6. Drill bore tool 0.4724 diameter.

7. Boring bar 80 mm diameter (1) T.C. blade and (1) T.C. chamfer blade 30°.

<u>Part No. 1246-301-0354</u>

1. Face mill 8.0" diameter 14 T.C. blades.

2. Drill T.C. 11 mm (0.433).

3. Boring bar 3.550" diameter (1) T.C. blade.

4. Boring bar 3.750" diameter (1) T.C. blade.

Part Nos. 1290-302-101, 1290-302-072, 1246-307-110

1. Drill 9 mm (0.344) T.C.

Part No. 1290-307-101

1. Shell End Mill 5.0" diameter 10 T.C. blades.
2. Boring bar 1.566" diameter (1) T.C. blade.
3. Boring bar 1.245" diameter (1) T.C. blade.
4. Boring bar 27 mm diameter (1.0625) x 34.5 mm diameter (1.360") and 2 chamfer blades.
5. Boring bar 32 mm x 35 mm (1.259 x 1.378) (1) T.C. blade each diameter.
6. Boring bar 40.3 mm (1.588") (1) T.C. blade.
7. Step drill 6.8 diameter (0.267" and countersink).
8. Tap m8 x 1.25; Drill T.C. 9 mm (0.344") T.C.

Part Nos. 1246-301-032, 1290-301-065

1. Spot Drill 0.50" diameter H.S.S.
2. Drill 0.937" diameter T.C. standard F.L.
3. Boring bar 0.990" diameter (1) T.C. blade.
4. Reamer 1.006" diameter T.C.

Part No. 1246-301-033

1. End Mill 3.0" diameter 6 T.C. blades 2" F.L.
2. Shell End Mill 6.0" diameter 12 T.C. blades.
3. Step drill 0.344 x 0.468" diameter.
4. Tap m10 x 1.5.

2.4 MODEL 007 CNC UNIT

2.4.1 Introduction

The control system proposed is a Computer Numerical Control System, Model 007. It uses integrated circuit electronics throughout and is built around a minicomputer which is an established, field-proven computer, and used in a variety of other applications in addition to numerical control.

The control unit is tailored to the machining center applications where tool data management requires a high degree of sophistication compatible with manufacturing system requirements. The tool data management feature in this control system supports random selection of tools up to eight digits, tool length compensation, feed-rate override, and tool usage monitor. These values become effective when the tool is loaded into the spindle.

The control units proposed in this quotation are four-axis controls. X, Y, Z contouring, B indexing. The CNC modular design of hardware and software provides system flexibility when it becomes part of a computer-aided manufacturing system.

2.4.2 Control Features

The following is a list of features which will be included in the control units for this manufacturing system.

2.4.3 CRT Display and Keyboard

A 32 x 12 character CRT is supplied on the CNC providing the user with a visual display of part program data, slide positions, spindle speeds, tool data, feed rates, error conditions and control diagnostic messages (in English). A full alphanumeric keyboard is provided with approximately eighteen additional function keys such as insert, delete, modify, shift, set inhibit, set dwell, etc. These, along with the CRT, provide valuable aids for system setup or debugging operations.

2.4.4 Linear Interpolation

In linear interpolation (G01), all axes simultaneously start and stop such that the machine is moved in a straight line. The axis data input in linear interpolation may be either absolute dimensions or incremental dimensions.

2.4.5 Circular Interpolation

When a G02 (clockwise arc) or G03 (counterclockwise arc) preparatory function is programmed, all axis data is executed in circular interpolation mode. Circular arcs up to one quadrant can be defined by one block of data for any of the three machine planes: XY, ZX, or YZ.

2.4.6 Helical Interpolation

Helical interpolation defines a method by which circular axis movements and a linear axis movement are processed under feed-rate control to produce a helical arc. Helical interpolation requires two axes to move simultaneously in such a manner as to generate a circular arc, while the third axis feeds at a controlled rate. The linear axis uses the I, J, or K words as the lead which is expressed in distance per radian.

Three types of information are required in a helical information block: the definition of the center of the arc, the definition of the lead, and the definition of the end-point of the arc.

2.4.7 Feed Rate Control

Two methods of feed-rate control are available for linear motions: feet-per-minute (FPM) and inverse-time (1/T). FPM is programmed with a G94 code and 1/T is programmed with a G93 code. The control prevents a program rate which would exceed the maximum contouring rate of any axis.

2.4.8 Input Range Checking

This feature provides part protection while enabling the programmer to define the range limits to the control which will be allowed at any given segment of the part program. The mnemonics SLO and SHI are used to define the most negative and the most positive range limits. If a command point is programmed which exceeds the limits, an error message is displayed and that block of data is not executed.

2.4.9 Rapid Traverse (Positioning Mode)

A G00 prep code is used to activate rapid traverse of the machine slides. The slides move at the maximum feed rate to the command position.

2.4.10 Automatic Acceleration/Deceleration (ACC/DEC)

In the positioning mode of operation, the control automatically accelerates up to the rapid speed on a linear slope and decelerates when it nears the final position. To minimize the time required to accelerate and decelerate, a combination step and linear slope is used.

On an ACC, the slide will step from zero to maximum feed rate and then execute a ramp acceleration to maximum rapid traverse rate. On a DEC, the slide will execute a ramp deceleration to the maximum feed rate and then execute a step to zero velocity.

2.4.11 Preparatory Codes

The following preparatory codes are supported by the control:

G00	Vector Rapid Traverse
G01	Linear Interpolation
G02	Circular Interpolation (clockwise)
G03	Circular Interpolation (counter-clockwise)
G04	Programmed Dwell
G17	Circular Interpolation X-Y Plane
G18	Circular Interpolation Z-X Plane
G19	Circular Interpolation Y-Z Plane
G70	Inch Input
G71	Metric Input
G90	Absolute Dimensional Input
G91	Incremental Dimensional Input

G92 Set Position

G93 Inverse-Time Feed Rate

G94 Feed-per-Minute Feed Rate

2.4.12 Miscellaneous Codes

The following miscellaneous codes are supported by the control unit:

M00 Programmed Stop

M01 Optional Stop

M02 End of Program

M06 Tool Change

M30 End of Tape

2.4.13 Plus/Minus Programming

Positive and negative axis dimensions may be programmed. Incremental or absolute data may be preceded by a plus or a minus sign. A positive sign is assumed when no sign is present.

2.4.14 Inch/Metric Switchable Input

Inch or metric input of data is provided by programming a G70 or G71 code. The CRT displays the data in the input units as selected.

2.4.15 Absolute/Incremental Input

The control can accept input in either absolute dimension form or incremental dimension form. A G90 code sets absolute mode, and a G91 code sets incremental mode. These codes are modal and may be intermixed within a part program.

In incremental mode, the position readouts remain absolute with the origin established by the last position set operation. Each incremental block is added to the readout dimension as it is executed.

2.4.16 Leading Zero Omission

Leading zeroes may be omitted for numeric data input. This feature reduces the amount of data that must be transmitted to the control.

2.4.17 Programmable Dwell

A G04 code is used to execute a programmed dwell. The dwell time may be programmed in the block with a G04 using the F-word with an F22 format. The range of the dwell is zero seconds to 99.99 seconds in 0.01-second increments. If no F code is programmed, a default value may be entered by the user as a system marriage parameter.

2.4.18 Program Stop/Optional Stop

A programmed stop is activated by an auxiliary function code M00. Machine action is stopped and a message is displayed at the end of the block containing the M00. To resume operation, a cycle start must be initiated.

2.4.19 Block Delete

When block delete is selected, any block of data containing a slash "/" as the first character is ignored. The control skips those blocks and executes the first block that does not contain a slash code. When the block delete function is off, all slash codes are ignored, and all data blocks are executed.

2.4.20 Operator Message Display

Four types of operator messages are used with this system. They are described as follows:

2.4.20.1 Parenthetic Data Input

Operator information may be coded within the part program text and displayed on the CRT. Operation of this featue is activiated by an MSG mnemonic. The message text can contain a maximum of 64 characters which are displayed on two lines of the CRT.

2.4.20.2 Auxiliary Data

Operator information may be coded within the auxiliary file associated with an NC program. Operator can request this program from the FMS control center via the CNC keyboard.

2.4.20.3 Command Data

Messages can be sent by the operator to the FMS control center by using the special function "FMS Command" key.

This function logically connects the CNC keyboard to the central FMS system. Any keyboard entry in this mode is transmitted to the FMS control center.

2.4.20.4 Central Control Data

Messages can be sent by the FMS control operator to the machine tool operator. The messages are displayed on the CRT of the CNC.

2.4.21 NC Data Input

The normal method of NC data input for the CNC controls proposed for this FMS is downloading of data from the FMS control directly into the CNCs. As an alternate method of data input, each control will be equipped with a tape reader to permit stand-alone operation.

In addition, the control will accept manual data input through the keyboard.

The machine tool operator tells the FMS system which part program is needed via a GET command and the eight-digit program ID. In full automatic mode, the FMS system uses a pallet reader at the machine tool to determine which part is to be selected.

2.4.22 Position Set

Alignment between the part program and the part are made by using either the special function key "Position Set" or by programming coordinate offsets by a G92 code. This feature enables the operator to define the program origin as any point within the machine range.

2.4.23 Grid Align

This feature provides for alignment of each contouring axis to its nearest electro-mechanical servo null to establish the relationship between the control and the physical machine position. Before performing this function, the operator must move each machine slide to a predefined position. After çompletion of the grid align operation, the part program coordinate system specified by the last position set operation is re-established.

2.4.24 Grid Offset

This feature allows the absolute coordinates (within the specified axis range limit) to be entered into the control for defining of the point to which the machine is to be aligned. This feature is used for setup purposes.

2.4.25 Power Feed/Incremental Jog

Power feed and incremental jog are manual controls initiated by switches which are externally mounted to the CNC. The power feed and the job controls permit positioning of one axis at a time. The jog selections are 0.0001", 0.001", 0.01", 0.1" or continuous.

2.4.26 Inhibit Set

Each axis may be prevented from moving by using the keyboard "Set Inhibit" special function key. When the "Set Inhibit" key is pressed, the inhibit state of all functions is displayed on the CRT. The inhibit state of an axis or function can be altered by entering a letter identification through the keyboard. This causes the indicated axis state to be reversed.

2.4.27 Axis Inversion

This feature allows mirror image parts to be produced from the same part program. Each contouring axis may be inverted by the use of the "Set Inversion" special function key.

2.4.28 Feed Rate Override

The "F" override key is provided to enter and override the feed rate in 1% increments from 1% to 999%. Subsequent program feed rates are multiplied by the override percentage. The effective feed rate is limited by the control to the machine maximum if the multiplied rate exceeds the machine capability.

The effective feed rate, either that programmed or that entered by feed-rate override, may be further modified by a potentiometer mounted on the machine panel. The potentiometer overrides the effective feed rate from 10% to 100%.

2.4.29 Rapid Traverse Override

This feature substitutes a reduced rapid traverse for all axes when active. If the rapid traverse override pushbutton is selected, the feed rate override potentiometer is active on rapid traverse spans to reduce the rapid traverse rate.

2.4.30 Single/Continuous Block Operation

The control can execute a part program from beginning to end in a continuous mode, or the control can be selected to execute one block of data at a time for setup or checkout purposes. Whenever single-block execution is in operation, the cycle start pushbutton must be pushed at the end of each block. Single-block mode is useful for program debugging or for making accuracy checks during production.

2.4.31 Automatic Target Point Align (TPA)

This feature provides an automatic procedure for moving the contouring axis to a predefined position so that the machine and the control can be synchronized. The TPA cycle is executed by pressing the TPA button. During this cycle, the machine contouring axes are moved, one at a time and in a predefined sequence, to the TPA limit switches. When all axes have moved to their TPA positions, a grid alignment cycle is automatically performed.

2.4.32 Dry Run

A dry run feature allows the part program to be cycled through a noncutting tryout cycle at a specified feed-rate override for debugging purposes. The control operates in the usual manner, except that all program feed rates are multiplied by a percentage constant that is input to the system as a marriage partner. The constant may have a value of 100% to 999%.

2.4.33 Servo Error Detection

Three levels of out-of-tolerance conditions are detected whenever a feedback error exists, namely, excess error, servo fail, and loop fail. Excess error will stop slide motion, whereas servo fail and loop fail will remove drive power. In each case, an error message is displayed on the control CRT and sent to the FMS control center for logging and additional processing.

2.4.34 In-Process Diagnostics

The series of in-process, "on-line" diagnostics is built into the control to perform a constant monitoring function on various activities and conditions within the control. If an error or malfunction is detected, an appropriate message is displayed on the control CRT, a CNC fault light is illuminated, and a machine shutdown is performed in an orderly manner, depending on the error severity level. The error condition is sent to the FMS control center for logging and processing.

2.4.35 Off-Line Diagnostics

A series of "off-line" diagnostic programs is provided with each control system. These diagnostic programs are provided in the form of test tapes and manuals which are used for fault isolation of the various hardware modules.

The tests are structured such that the CRT will prompt the technician as to the required inputs. The conclusion of the test is then displayed on the CRT. The description of operation for each diagnostic is contained within the Maintenance Manual. These tests are conducted at the machine site using the CNC tape reader, CRT, and keyboard.

2.4.36 Tool Data Management

Included in the controls for this proposal are tool identification, tool length compensation, and tool usage monitor. The following is a description of each functon.

2.4.36.1 Tool Identification

Permits tools to be specified in the part program as catalogue numbers up to eight digits, rather than as a specific storage pocket location. This allows tool number programming to be independent of job setup since the operator assigns the tools to the pocket location.

2.4.36.2 Tooling Parameters

Provides management of tooling parameters such as length, feed-rate override, spindle-speed override, and tool usage which are kept for each of the tools. These values automatically become effective when the tool is loaded into the spindle. No special programming or operator action is required to activate this data.

2.4.36.3 Tool Usage Monitor

Provides the ability to monitor the actual tool usage time as compared to a predicted tool life for that particular tool. Whenever the predicted life of a tool is exhausted, a message is transmitted to the FMS control station which will output an alarm condition.

The control can, if required, automatically select a redundant tool for subsequent operations, or request that a new tool be loaded. A redundant tool is another tool with the same identification number. Any number of redundant tools may be loaded into the mechanism. This way, duplicate tools can be loaded for long job runs.

2.4.36.4 Tool Data Entry

Tool data entry is performed through the CNC keyboard in an English-like, conversational data entry method and checked on the CRT display.

2.4.37 Slide Feedback

The machine slides will be equipped with inductosyn scales. The output resolution of each slide will be 0.00005 inch.

2.4.38 Jog Auto Return

This feature permits the operator to interrupt a machining cycle and to power feed away from the part. Moves may be made in the X, Y, or Z axes to clear the cutter for viewing. Holding in the cycle start pushbutton will return all axes simultaneously at maximum jog rate to the point at which the cutter left the program. At this point, the cycle is restarted at programmed feed rate.

2.4.39 FMS Pallet Offsets

FMS pallet offset feature provides the capability for automatic adjustments to compensate for fixture or workpiece misalignment via the CNC fixture offset feature. The X, Y, and Z offset groups have a range of ±99.9999 inches (±999.999 millimeters). The value is activated by a two-digit programmed H code and is added to the programmed moves. Adjustments of the offset value are automatically made by the control system when the fixture is rotated by multiples of 90°.

The pallet (X, Y, Z) offsets are stored at the FMS control center and will be sent to the CNC from the data distributor before transmission of each NC program.

2.4.40 NC Program Editing

The CNC unit has a very powerful editing capability. Edit corrections can be stored in the CNC memory and used when the program is run, or edit corrections can be made to the NC program and source program which are stored in the FMS computer system. When using a fully automatic FMS, part program edits should be made via the FMS edit program so that the corrections are stored on the central computer. By doing this, the part can be run on other machine tools with the same edit corrections included.

The CNC edit permits part programs to be modified at the control. Both tape and stored programs can be edited.

Edit permits existing blocks to be completely deleted or individual letter address fields to be added, deleted, or modified. New blocks may also be inserted between blocks.

To perform an edit function, the operator constructs an edit data file in memory which specifies the modifications to be made. Entry of this file is performed in a conversational manner, using the CRT and keyboard. Special function keys for modifying, inserting, and deleting data are provided to minimize operator input, and their functions are echoed on the CRT as this edit data file is being formed.

Up to 1024 bytes of memory may be used for the edit data file. A typical operation, such as changing axis dimensions, requires about 25 bytes of storage, depending on the dimensions changed. Therefore, approximately 40 blocks may be changed.

Once the edit data file has been constructed, it may be selectively enabled or inhibited by a pushbutton selector. When enabled, the part program will be modified as specified. When inhibited, the part program will be executed without modification.

The contents of the edit data file may be cleared by pressing the EDIT BUFFER CLEAR pushbutton while in the edit mode.

2.4.41 Fixed Cycles G80 Series

This feature provides the G80 series of fixed cycles as defined by EIA Specification RS-274C. All of the G80 series operations are provided except G83 (deep hole drilling). These cycles are defined as follows:

G79	Mill Cycle
G80	Cancel Cycle
G81	Drill
G82	Counterbore
G84	Tap
G85	Bore No. 1 (w/Feed Retract)
G86	Bore No. 2 (w/Stop and Rapid Retract)
G87	Bore No. 3 (w/Stop and Manual Retract)
G88	Bore No. 4 (w/Dwell, Stop, and Manual Retract)
G89	Bore No. 5 (w/Dwell and Feed Retract)

2.4.42 FMS Interface

The control will include the necessary hardware and software to interface to an FMS. The interface will provide two-way communication via an RS-232 asynchronous communications controller.

2.4.43 Tool Data Tape Input

This feature allows tooling data to be entered into the control system as a separate tooling tape or by downloading from the FMS. This option relieves the machine operator from the task of individually inserting tooling data through the system keyboard, thereby saving time and reducing errors.

The tool identification, pocket location, length, manual load flag, tool cycle time, spindle-speed override, feed-rate override, cutter diameter compensation, and the common tool designator may be input to the system via the tool data tape.

2.4.44 CNC Initial Program Load

The initial CNC load tape is loaded into the control at the machine site using the control's CRT, keyboard, and tape reader.

2.4.45 Training

A maintenance training class is provided with this FMS on the CNC system. It is aimed toward giving technicians a familiarity with the control, acquaint them with trouble-shooting techniques, and teach adjustment procedures.

2.4.46 Environmental Specifications

The control system will be equipped with air conditioning and will operate from temperatures from 40° to 125°F and relative humidity 5% to 95% without condensation. The permanent-type filter on the air conditioner is monitored and, if it becomes clogged, a warning is displayed on the CRT.

2.5 MATERIAL HANDLING

2.5.1 Introduction

The material movement within an FMS is a key factor in the total productivity of the company. Without controlled material movement within the manufacturing shop, wasted utilization occurs in manpower, floor space, and machine tools. The level of optimization of these factors will greatly influence the justification of capital dollars being spent on this system. For these reasons, we have made intensive studies on the type of material handling equipment best suited for this FMS.

Analysis of powered-roller conveyors, tow chains, shuttle carts, and wire-guided carts was made. The final selection of the type of material transport system to be used in this system is the wire-guided cart with direct computer control.

2.5.2 Reasons for Selection

The material handling system must have characteristics which lead to flexibility of machine layout and part mix. It must integrate to many varieties of equipment in this FMS and in other areas of the manufacturing shop. It must be highly reliable, fast, and easy to maintain. The wire-guided cart method of material transport meets these criteria better than the other available methods.

In addition, the weight of the parts, pallets, and fixtures fit within the 3,300-pound capacity of the carts and leaves sufficient room for variations of the part mix. The physical size of the pallets can be easily accommodated by this system while, at the same time, floor space constraints are minimized.

2.5.3 Description

The wire-guided carts for this FMS are manufactured by ABC Corporation. This cart concept has been employed in manufacturing and warehousing operations for nearly twenty years in both Europe and the United States. We have made arrangements for sales, installations, and services of this equipment in FMSs.

The wire-guided cart is an unmanned, battery-powered unit which receives its commands from wires embedded in the floor. A stand-alone minicomputer controls the direction and location of travel of the cart while the FMS computer determines which machine stations are to be serviced and when they are to be serviced. This control is through radio frequency signals in the wires in the floor and antennae mounted on the carts.

Additional machine stations may be added to this system by simply installing a small group of wires in a slot in the floor. A layer of epoxy then fills the cut in the floor.

2.5.4 Specifications

Carrier Size	83" long with bumpers. 48" wide. 23" high for basic unit.
Capacity	3,300 lbs. for part, fixture, pallet, and load adapter.
Lifting Height	1" rise with hydraulic locators. 4" rise with table lift (optional).
Travel Speeds	40, 100, 200 ft. per minute.
Turning Radius	2 ft. minimum at 40 fpm speed.
Batteries	48 volt, 10-hour average life.
Safety Equipment	Flexible bumpers mounted 15" extended on front and back. 12" stopping distance at full speed. Yellow caution beacons on front and back.
Load Deck	Powered rollers for stationary deck. Load beams for optional hydraulically-lifted deck.
Steering Control	Command signals from the computer through guidance antennae or manually-operated pendant control.
Locating Devices	Four sets of hydraulically-actuated jacks on the cart located on small metal cones mounted on the floor.
Computer Control	A Digital Equipment Corporation PDP-11 minicomputer controls direction and location of the carts. Com-

plete interface is supplied to tie this minicomputer to the FMS central computer system.

2.5.5 Load Handling

Automatic, unmanned load handling is accomplished by two possible methods. First, load handling is accomplished by picking up or depositing the load at a work station. The carrier picks up a load by driving under it, raising the load bearing platform to lift the load clear of the pickup and delivery station, and then driving away. The carrier delivers a load by driving into the load station with the load bearing platform elevated and then lowering the load onto the pickup and delivery stand.

Second, for systems without the optional lift capability of the load platform, power rollers are mounted on the cart. The pallet is rolled on and off the cart from similar rollers at the work stations.

In both cases, electrical switches on the cart assure proper pallet position before the cart is moved.

2.5.6 Stopping

The cart is brought to a stop by decelerating the drive motors and applying the brakes. The brakes are also used to hold a stopped carrier in place on the guidepath. Since stopping is not servo-controlled, positioning accuracy along the path is about ±1 inch. Repeatability of the stop position is affected by load weight, floor finish, and condition of the brakes.

For accurate stopping at the machine station delivery and discharge areas, centering jacks on the cart are actuated and located on precision cones mounted on floor plates.

2.5.7 Operating Speeds

The cart will operate at three nominal speeds: 40, 100, and 200 feet per minute. The speed of the carrier is primarily limited by the layout of the guidepath. The electronics control package on board the carrier provides for controlled acceleration and deceleration. The commands for changing speeds are received by reading a coded pattern of steel plates affixed to the floor along the path of the cart.

2.5.8 Guidance System

The cart is guided along its path by following an energized guide wire embedded in the surface of the floor. The guide wire is energized with a very low frequency radio signal of about 10 kilohertz. This signal is not radiated, but the magnetic field can be reliably detected within about 6 inches of the wire.

Construction rod or screen in the floor does not seriously effect the guidance field, however, large steel plates or grating must be kept away from the immediate vicinity of the wire.

The guide wire and signal wires are installed in a slot saved approximately 1.5 inches deep in the floor. The wires in the slot are protected by a gasket and epoxy grouting. The grouting slot restores a smooth surface to the floor.

Coded command signals, such as to actuate the locating jacks or raise or lower the platform, are transmitted to the cart through energized wire loops located in the floor at each stop.

2.5.9 Safety

The cart is a very simple and safe material handling device. The system software prevents a cart from entering into a segment of track that contains another cart.

Yellow caution beacons are mounted on the front and back of the cart They flash when the cart gets ready to move and continue throughout the move.

A safety bumper prevents injury or damage to objects in its path. The flexible bumper extends 15 inches both front and rear of the cart body. A cart traveling at any speed will come to a complete stop within the compression distance of the bumper. The safety bumpers are only to be used for stopping in emergency conditions. Emergency stopping from the fast speed is achieved with a higher than normal deceleration.

2.5.10 Normal Operation

An operator can exercise control over the cart system by using an I/O terminal connected to the minicomputer. In case the FMS central control is disconnected, the operator can dispatch the cart to any location by use of the I/O terminal.

The cart has a hand-held, plug-in control unit by which the operator can manually direct the carrier to perform all activities. The cart can be moved away from the wire path by use of this control.

2.5.11 Batteries

The cart is powered by self-contained, industrial-grade, lead-acid storage batteries. Due to the operating strategy of the system and normal charge life of the batteries, each cart will operate approximately 10 hours on one charge cycle. If, during the operating shift, the battery power becomes too low to operate the carrier effectively, the systems operator will be notified via a status message from the computer. The carrier will automatically take itself out of service and move to the battery charge area.

Each carrier should have at least one set of spare batteries which should be kept charged at all times. This would allow the operator to replace the low battery with the fully-charged set, an operation which takes approximately 8 minutes.

2.5.12 Equipment List

This system proposal includes the following list of equipment:

3	Carts
3	Frequency Shift Keying (FSK) units.
1	Frequency generator.
1	Complete set of DEC PDP-11/34 equipment.
1	Complete set of RTS software for system operation.
1	Field wiring, includes material and service/installation.
9	Sets of batteries.
1	Set of battery-charging equipment, consisting of 3 charging units and 9 battery carts to move batteries.
1	Documentation, manuals and drawings (complete set).
1	Project engineering and field supervision.

This proposal assumes the following conditions:

- No floor problems at the customer's plant.
- Carts will run inside building.
- Electrical power within 20 feet of site.
- We will provide application software.
- Customer to supply all vents, hoods, water supply, and wash stands for the battery-charging stations.
- We assume complete responsibility for the installation and operation of the material handling system.

2.6 FMS OVERALL SYSTEM CONTROL

2.6.1 System Philosophy

The proposed flexible manufacturing system includes many capabilities in providing solutions to manufacturing problems. Among these capabilities are:

- Remote distribution of NC data to machine tool controllers.
- Management of pallet and tooling storage.
- Delivery of workpieces to the machines.
- Maintenance of NC program libraries.
- Maintenance and trouble-shooting of system facilities.
- Link to distant data processing facilities.

In order to develop and enhance these capabilities, the architecture requires modularity. This same modular approach enables a customer to proceed in much the same manner in implementing a multimachine manufacturing system of computers or functions having distributed intelligent controllers. This modular concept, inherent in a network of distributed intelligent controllers, lends itself to phased installation which is a vital requirement for any manufacturing control system.

Other major design philosophies being followed include:

- Utilization of standard computer hardware and software components.
- Customization of system by the customer where possible to minimize tailored applications.
- Modular growth capabilities in both capacity and capabilities.
- Manageability via a shop- or user-oriented language.
- Security of critical or sensitive data.

2.6.2 Overview of the FMS

The proposed flexible manufacturing system is a computer-controlled random parts manufacturing system consisting of standard numerically-controlled machine tool modules and other work stations linked together by a parts handling system.

This system provides many capabilities for solving manufacturing problems. Among these are:

1. Remote distribution of NC programs and data files to machine tool controllers.

2. Maintenance of NC program libraries.

3. NC part processing at remote facilities via telecommunication links

4. Automated delivery of workpieces to work stations.

5. Management of pallet and tooling data.

6. Modeling of system activities to make resources available to achieve the required production.

7. Scheduling, preparation and staging of job lots to be entered into the system.

8. Diagnostics for maintenance and trouble-shooting of system facilities.

9. Recording of accounting data and formatting management reports from that data.

The system is designed in a modular fashion which lends itself to phased installation, allowing the user to begin using the system while other portions are still in the planning or implementation stage. In some modular combinations, automated or "unmanned" operation of certain portions of the system is possible.

The system is designed around the Digital Equipment Corporation's PDP-11 series computer family which offers compatibility of software from the smallest computers in the line to the largest. As requirements grow, overall system capacity can be increased by adding internal storage, disk storage, or upgrading to a larger and faster PDP-11 computer.

Figure 2 on page 83 is is a diagram of the FMS showing all the functions available.

2.6.3 Basic Functions

The basic functions which reside in the FMS central control computer operate from a common data base and are normally invoked by commands entered by authorized system users at terminals connected to the system. In unmanned systems, the Traffic Coordination function automatically invokes the Data Distribution function.

The basic functions include:

1. Data Distribution

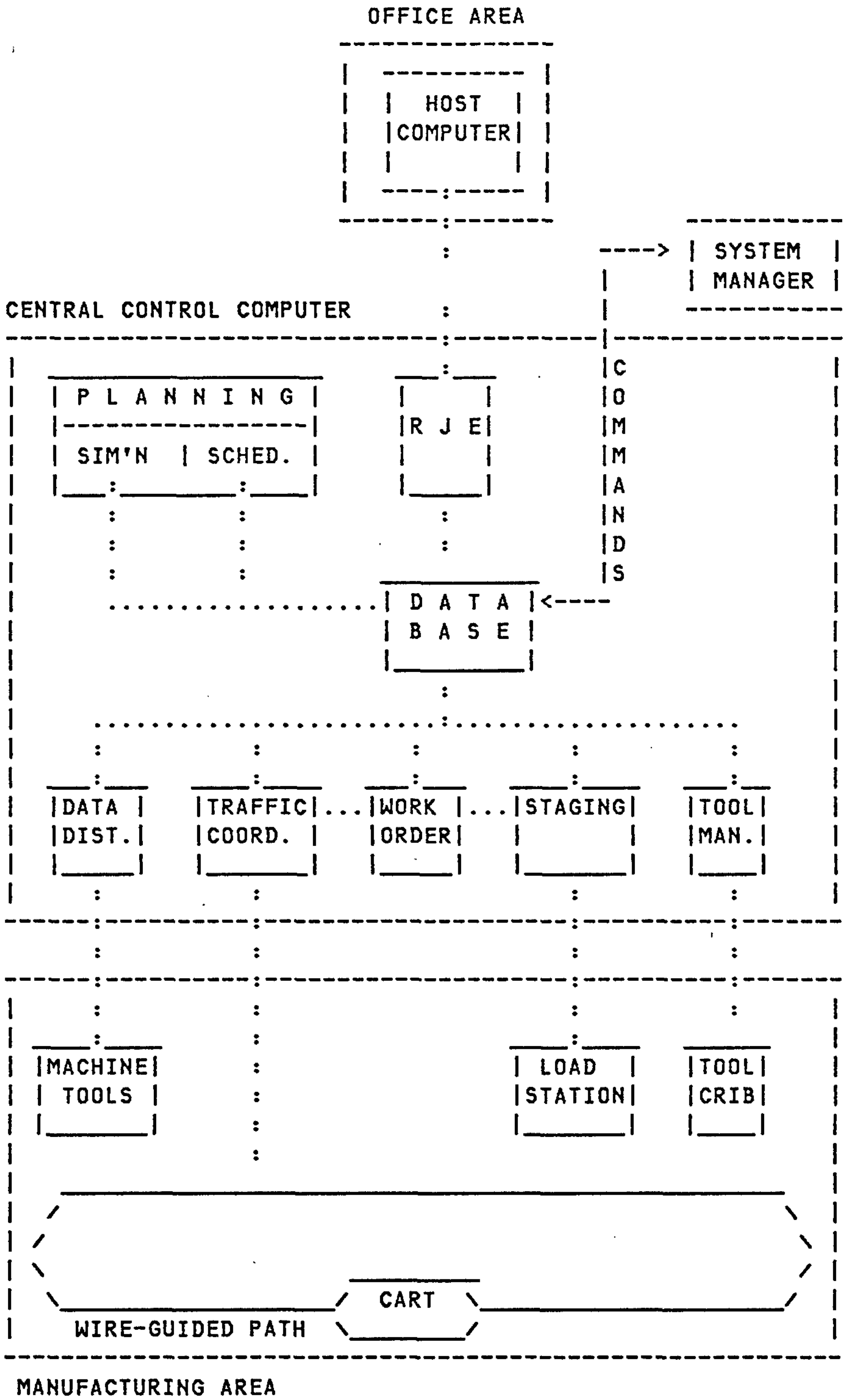

Figure 2. Flexible Manufacturing System Diagram

Sends data to and receives data from the Machine Tool Controllers. Also incorporates the capability to manage the data stored on the system and used by other functions, i.e., load, copy, alter, edit, and delete. This function, commonly known as the Base System, is the only function which can reside alone. Required in every system.

2. Remote Job Entry (RJE)

   An option available with Data Distribution, this function enables communications between the central computer and the user's remote part-processing computer, if applicable. Optional

3. Traffic Coordination

   Controls the movement of workpieces between work stations within the system. Required in unmanned systems. Optional in manned systems.

4. Work Order

   This function is used to describe batches of workpieces to a system to exercise control over the authorization of those workpieces for processing. Required and used only in systems with Traffic Coordination.

5. Staging

   Controls the point of entry and exit of workpieces at the staging area of a system. Required and used only in systems with Traffic Coordination.

6. Tool Management

   Stores, manages, and updates tool data files which contain tooling data, i.e., length and diameter compensations, life expectancy, etc. Optional.

7. Planning

   The Simulation and Batch Scheduling functions fall into this category.

   a. Simulation

      Allows the user to model the activities of a system so that the proper resources can be made available to accomplish the required production. Optional.

   b. Batch Scheduling

      Allows the user to schedule batches of parts in the appropriate mix through a production system in order to meet due dates and maintain acceptable utilization of resources. Optional. Not available at this time.

The basic functions that reside in a given system are specified during a process called SYSGEN, which is an interactive session between computer and user defining the attributes of the system.

Provided with the system will be manuals which describe the features of the system and each of its basic functions.

2.6.4 System Features

This proposal is based on the specifications provided by XYZ Corporation and includes those described herein.

2.6.5 Data Distribution

The Data Distribution provides facilities for loading, manipulating, and transferring NC data for machine tools connected to the system.

The Data Distributor provides the capability to:

1. Store NC programs and associated data, i.e., tooling data, messages, setup data, etc.

2. Transfer part programs to connected machine tool controllers (MTCs) for execution.

3. Transfer single or multiple part programs to internal flexible disk drives within connected MTCs for execution at a later time.

4. Load, alter, copy, delete, and edit NC programs and associated data from the central computer site or from the shop floor.

5. Log data transfer and command usage.

6. Display NC program status.

7. Display status of machine tools in the system.

8. Display standard format reports or special reports formatted from the system log and other available data.

9. Send messages from one terminal or MTC to one or all terminals and/or MTCs in the system.

10. Communicate via the RJE option from the central computer to other computers designated by the user to perform part programming operations. Full implementation of the telecommunications feature depends upon the computer that the user is currently using to do part programming.

2.6.6 Computer-to-Computer Communications

The FMS central computer has the capability to communicate with other computers which use the IBM 2780 protocol and are remote to the central computer site. This option, commonly called RJE, is desirable when the user performs NC part processing on a remote computer and wishes to transmit the processed output to the FMS computer to be stored for execution at a later time. This allows a tapeless environment to be maintained. By adding the RJE capability, the user can:

1. Create, store, and edit part programs on the FMS computer to at the remote (host) computer if the programs are stored there.

2. Initiate APT processing and post-processing:

    a. At the FMS computer, by using the RJE to transmit the source program from that computer to the remote computer.

    b. At the remote computer, by running APT against the source program which is already stored at the remote site.

3. Transmit the processed output and associated data from the remote computer via RJE to the central computer for storage.

Programs stored in this manner can, in a manned environment, be initiated by operators at any of the Machine Tool Controllers (MTCs) which are part of the system. In a system where the machines are unmanned, the correct part programs are transmitted to the correct MTC when a palletized part enters the center section to be machined.

2.6.7 Traffic Coordination

Traffic Coordination provides the control to move a workpiece between work stations. These work stations can be machining stations, inspection stations, load/unload stations, or any other station types. Using the routing previously defined by the Work Order Processor, routing of workpieces within the system is optimized in order to minimize machine idle time.

The Traffic Controller provides the following features:

1. Automatic and manual pallet dispatching.

2. Control of horizontal movement of all pallets in the system.

3. Inquiry into the status of Traffic resources, i.e., shuttle mechanisms, pallets, and carts.

4. Automatic reporting.

5. System modeling.

6. Automated initiation of data transfers from the Data Distributor to the MTCs in automatic mode.

2.6.8 Tool Management

Tool management, at this point, contains only the Tool Kit Manager feature which stores tool data, provides the management capability, and transmits tool data directly to an MTC.

The Tool Kit Manager provides the capabilities to:

1. Add new tool kits to the system.

2. Automatically enter data directly from an Electronic Tool Gauge.

3. Display and allow editing of current tooling data.

4. Assign a kit ID to a list of tools generated by the post-processor.

5. Associate previously loaded tooling data with each tool loaded into a machine's tool matrix and identify the tool pocket that holds the tool.

6. Identify the pockets in a specific machine's tool matrix from which tools have been removed in the unload process.

7. Display the list of tools within a kit.

8. Display kit status.

9. Search the list of kits for a kit containing a specific list of tools.

10. Delete kits from the system.

2.6.9 Work Order Processor/Staging Manager

The Work Order Processor provides the automated capability to manage the FMS production environment. It uses work orders and routing sequences to implement various workpiece schedules and operating strategies.

The Work Order Processor provides the capabilities to:

1. Define an individual work order to the system and describe its routing or station processing sequence.

2. Control the introduction of workpieces by interaction with the Staging Manager.

3. Start and stop the processing of an individual work order.

4. Allow the Load Station Operator (LSO) to enter pallets and fixtures into the system's pool of available resources.

5. Allow the LSO to remove pallets or fixtures from the system's pool of available resources.

6. Recall current and historic information about completed and in-process work.

The Staging Manager controls the point of entry and exit of the workpieces at the staging area of an FMS system.

The Staging Manager provides the LSOs with the capabilities to:

1. Receive a list of pallet load alternatives.

2. Receive instructions pertaining to pallet/fixture load/unload.

3. Identify the workpiece(s) on a pallet prior to entering the pallet into the system.

4. Communicate with the Work Order Processor to update workpiece statistics.

5. Fetch a pallet from a parking area.

2.6.10 Planning

The Planning function in the FMS is made possible by two independent but related functions: Simulation and Batch Scheduling.

Batch Scheduling, as mentioned earlier, is not available at this time.

The General Simulation Model provides the simulation capability. It is a general model of FMSs which can be used to quickly analyze the performance of an FMS with respect to workpiece flow. The analyst, who need not be a specialist in simulation techniques, simply defines what physical components exist in the system being analyzed and what interactions exist among the system components.

The General Simulation Model gives the analyst the capability to:

1. Learn quickly how to obtain useful results in hours, rather than weeks, since the concern is with modeling a system and analyzing its performance, rather than programming a simulation.

2. Obtain perforamnce data from each simulation run which will answer questions about the particular configuration being modelled. By using a case study approach, answers can be obtained to the following typical questions:

   a. How many machines, local queues, pallets, and workpiece carriers are needed to satisfy production requirements?

   b. For a particular FMS configuration, how should production be scheduled to satisfy management objectives?

   c. How sensitive is the system performance with respect to machine and workpiece carrier failures, variable machining cycle time, and material handling congestion?

   d. How does a limited amount of direct labor, in the form of a load station operators, affect system performance?

3. Define FMSs which fall into a general class structure supporting:

   a. Standard NC machines having single-center sections and local queues

   b. Automated material handling for management of workpiece movement using wire-guided carts or power-roller conveyors.

   c. Palletized workpieces with up to four workpieces per pallet using dedicated, common, or progressive setup fixtures.

   d. The work order concept which, by workpiece type, allows the specification of lot size, start and due dates, operation routing sequences, and pallet/fixture characteristics.

2.6.11 Special Considerations

2.6.11.1 Installation

The customer must provide a suitable facility to house the computer and its peripherals, adhering to the environmental specifications provided by us. Our pricing includes installation of the equipment in this facility. It does not include the electrical wiring required to make the computer operational. This is the customer's responsibility. We will provide the connectors for the equipment and specifications on the wiring required for the installation.

2.6.12 Options for Performing NC Part Program Modifications

The standard FMS is quoted here with paper-tape reader to accept part programs created at another site. Using the LOAD command, the user simply loads the new part program via paper-tape reader into the FMS central computer, replacing the old verson.

Optionally, the user can purchase the necessary hardware and software to implement a 2780 communications link between the FMS computer and the remote part-processing computer. Upon completion of processing at the remote site, the output would be transmitted to the FMS central computer for storage.

A second option requires the user to purchase the necessary hardware and an APT compiler which will execute on the FMS central computer. In this way, part programming is confined to a single site. Although offering this option, we will not guarantee that the required system throughput can be maintained when the APT compiler is in use.

In addition to the standard hardware and software, the necessary hardware and software to implement the proposed options will be quoted in this proposal.

2.6.13 Computer Hardware and Software Required

The following computer hardware and software is necessary to accomplish the requirements described above:

2.6.13.1 Computer Hardware

1	PDP-11/44 Computer System with 256 words of MOS memory
1	67 MB Disk Drive
1	1600 BPI Tape Drive
1	1200 Baud Console
1	300 LPM Printer
6	VT100 Terminals (3 for Load Stations)
	*RT-100 Shop-Hardened Terminal Extra
	*Switchable Screen Feature for MTC Display also Extra
1	Paper-Tape Reader/Punch
6	Machine Connects
6	Terminal Connects

2.6.13.2 Computer Software

1	RSX-11M Plus Operating System
1	FORTRAN-IV Plus Compiler
1	DECNET-11M Plus
1	Standard Operating System

2.6.14 Optional Equipment Required for RJE

1	2780 Interface Board
1	Hardware CRC Unit
1	RSX-11M/2780 Software Package

2.6.15 Optional Equipment Required for APT Compiler on FMS Computer

1	256 Words Additional MOS Memory
1	67 MB Disk Drive
1	UCC APT Software Package
1	UCC Post-processor Software Package

2.7 PROJECT MANAGEMENT AND PLANNING SYSTEM

The customer's management team must maintain close coordination with us throughout the project in order to protect their sizeable investment and assure a most successful implementation of this project. We, as the vendor, recognize this need and are capable of managing a project of this nature.

We use a project manager concept along with a computer-based PERT-like Systems Planning Network to enable us to provide flexible manufacturing systems to our customers in a timely, accurate, and professional manner.

Upon receipt of your order, a system project manager will be appointed whose responsibilities center around the total success of this project. In addition, functional project managers will be appointed from the line organizations which are involved in this project. Applications engineering, mechanical engineering, electrical engineering, NC engineering, production control, manufacturing, etc., will each appoint a functional project manager to work on the project team and report to the project manager.

Responsibilities of this team and the project manager are the preparation of detailed plans suitable for monitoring the progress of all key events in the project. Day-to-day administration of all facets of this project include design, manufacturing, documentation, training, service, and spare parts. There will be regular reporting of project status to our management and customer management. Finally, we will determine all actions and alternative plans to keep this project on schedule and within the needs of the customer.

The PERT-like project management system being used to control all aspects of this project is conceived as a way to present information to all parties so that they may act more quickly and accurately with the real facts at hand. This computer-based management system uses network description data prepared by the project functional managers. Critical path scheduling techniques are used to determine lead times, slack periods, earliest completion dates, and alternative courses of action. This system provides current reports of the network operation to aid the project manager to efficiently plan the project and schedule the tasks and resources required to complete the project. An hour's reporting scheme is used to map progress against the network, and alternative plans can be evaluated before implementation. The proejct schedule or time frame, shown in Figure 3 on page 93, is generated using this system.

With the techniques of project management and computer-aided planning, we assure the customer of a professional and efficienct method of systems planning. Such systems planning is the key to success of this project and is certainly one of the main elements necessary to protect the investment and trust of the customer.

2.8 DOCUMENTATION

Two sets of the following technical manuals will be included:

1. Machine Documentation

    a. Operator's Manual for each machine.

    b. Machine Maintenance Manual, including machine specifications, functional diagrams, installation instructions, and machine adjustments.

2. CNC Control Documentation

    a. Basic Part Programming Manual

    b. CNC Control Maintenance Manual

    c. Diagnostic Tapes

    d. Load System Tape and Documentation

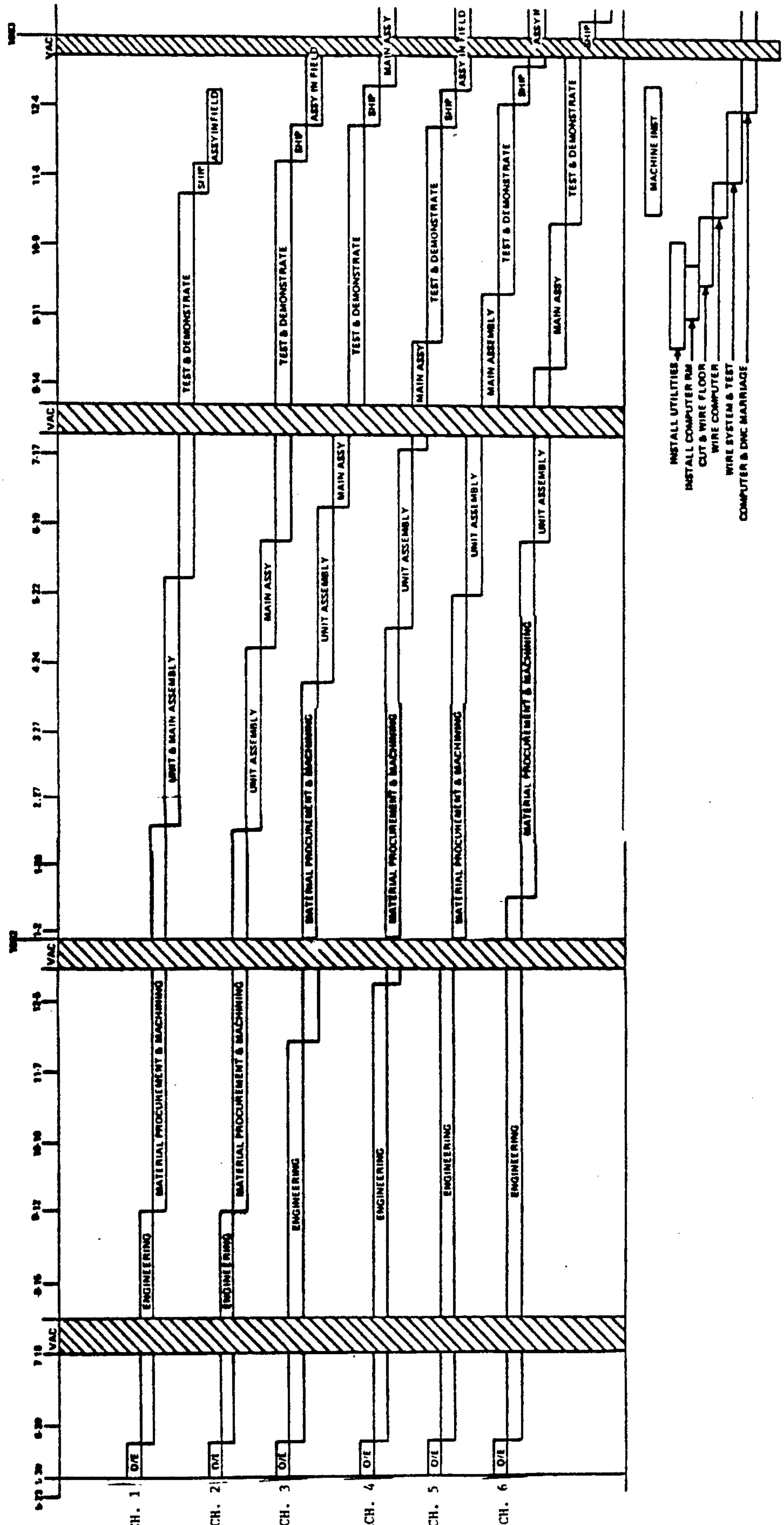

Figure 3. Project Time Frame Chart

3. FMS Central Computer Documentation

   a. Functional Specifications

   b. Architecture Specifications

      - Describing structure of system.
      - Individual programs.
      - Data structures.
      - Internal operation of system.

   c. Operator's Manual.

2.9 RESPONSE TO CUSTOMER SPECIFICATIONS

We do not have complete information to respond to XYZ Corporation's special requirement specifications at this time. We will respond as soon as complete information is available.

2.10 PART PROCESS AND TIME STUDY SHEETS

2.10.1 Assumptions

2.10.1.1 Production Hours

24 hours per day at 65% efficiency.

2.10.1.2 Material

In the absence of material specifications, we are assuming grey cast iron - 200 BHN.

2.10.1.3 Stock Removal

Average 0.19"

2.10.1.4 Cutting Speeds

Cutting Speeds

Drilling - High-Speed Steel	80	Surface Feet per Minute (S.F.M.)
Drilling - Carbide	170	S.F.M.
Reaming - Carbide	120	S.F.M.
Tapping - High-Speed Steel	30	S.F.M.
Milling - Rough	250	S.F.M.
Milling - Finish	350	S.F.M.
Boring - Rough	250	S.F.M.
Boring - Finish	350	S.F.M.

2.10.2 Part I: Summary

Cycle Time Distribution

Part Name	Part Number	Cycle Time
Retainer	1290-302-101	Four parts mounted in fixture, average cycle time per piece: 1.8 minutes. Cycle time per pallet/fixture: 7.2 minutes.
Retainer	1290-302-072	Four parts mounted in fixture, average cycle time per piece: 1.8 minutes. Cycle time per pallet/fixture: 7.2 minutes.
Retainer	1246-307-110	Four parts mounted in fixture, average cycle time per piece: 1.64 minutes. Cycle time per pallet/fixture" 6.56 minutes.
Cover	1246-301-350	Two parts mounted in fixture, average cycle time per piece: 2.68 minutes. Cycle time per pallet/fixture: 5.36 minutes.
Housing	1290-307-001	One part mounted in fixture. Cycle time per piece: 10.26 minutes.
Tower	1246-301-068	First setup: One part mounted in fixture; Cycle time per piece: 3.92 minutes. Second setup: One part mounted in fixture; Cycle time per piece: 3.25 minutes.

Bell Cover	**1246-301-032**	One part mounted in fixture. Cycle time per piece: 7.44 minutes.
Bell Cover	**1246-301-065**	One part mounted in fixture. Cycle time per piece: 7.44 minutes.
Main Housing	**1246-301-037**	One part mounted in fixture. Cycle time per piece: 5.07 minutes.

Cycle time is defined as the time a pallet/fixture is occupying the work station of the machining centers for the purpose of processing parts.

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Retainer	1290-302-101 and 1290-302-072
		MATERIAL: Cast Iron	RELEASE SHEET 1 OF 1

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture - 2 of each part number	in fixture								
1	Drill 11 holes 9 mm dia.(0.359")	T. C. Drill 9 mm diameter			180	1915	.0065	12.4	.75"	0.90
	Position 10 times									0.60
	Position to second part									0.10
	Repeat									1.50
	Index Fixture 180^o									0.20
	Repeat two pieces									3.10
	Index to exit									0.20
	1-Tool Change									0.40
PROCESS ENGR.									TOTAL TIME	7.00

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EXAMPLE PROPOSAL FOR AN FMS TO MACHINE PRISMATIC PARTS

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Retainer	1246-307-110
		MATERIAL: Cast Iron	RELEASE SHEET 1 OF 1

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture - 4 parts in fixture									
1	Drill 10 holes 9 mm dia.	T. C. Drill 9 mm dia (0.359")			180	1915	.0065	12.4	.75"	0.80
	Position 9 times									0.54
	Position to second part									0.10
	Repeat									1.44
	Index Fixture 180°									0.20
	Repeat two parts									2.88
	Index to Exit									0.20
	1-Tool Change									0.40
PROCESS ENGR.									TOTAL TIME	6.56

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PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Cover	1246-301-035
		MATERIAL: Cast Iron	RELEASE SHEET 1 OF 1

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture - 2 Parts in fixture side by side									
1	Mill Face 2 pieces	Face Mill 8.0" dia 14 T.C. blades			250	120	.112	13.44	21.0"	1.60
2	Drill 4 Holes 11 mm dia (0.433")	T.C. Drill 11 mm dia.			180	1585	.007	11.10	.70"	0.36
	Position 3 Times									0.18
	Position to second part									0.08
	Repeat									0.54
3.	Bore 95.25 mm dia (rough)	Boring Bar 3.55" dia 1 T.C.T.			250	255	.006	1.53	.31	0.22
	Position to second part									0.08
	Repeat									0.22
4	Bore 95.25 mm dia (finish)	Boring Bar 3.75" dia 1 T.C.T.			350	355	.005	1.77	.31	0.20
	Position to second part									0.08
	Repeat									0.20
	4-Tool Changes									1.60
PROCESS ENGR.									TOTAL TIME	5.36

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EXAMPLE PROPOSAL FOR AN FMS TO MACHINE PRISMATIC PARTS

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Gear Change Housing	1290-307-001
		MATERIAL: Cast Iron	RELEASE SHEET 1 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture 1 Part									
1	Mill Face and end	Shell End Mill 5.0" dia.			250	190	.180	15.2	12.75	0.85
	Index 90° to end	10 T.C. Blades								0.20
	Mill End								3.30"	0.25
2	Bore 40.3 mm dia (rough)	Boring Bar 1.566" dia.			250	600	.006	3.6	1.76"	0.52
		1 T.C. Blade								
3	Bore 32.0 mm dia. (rough)	Boring Bar 1.245" dia.			250	765	.006	4.6	1.2"	0.30
	Index 180°	1 T.C. Blade								0.20
	Bore Other End								2.19"	0.50
4	Finish Bore 27 mm dia and	Boring Bar 1.063" dia. x			250	700	.006	4.2	.80"	0.28
	chamfer 2 places, semi-finish	1.358" and 2 chamfer blades								
	35 mm dia.									

PROCESS ENGR.	TOTAL TIME

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PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Gear Change Housing	1290-307-001
		MATERIAL Cast Iron	RELEASE SHEET 2 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
5	Bore-Finish 30.0 and 35.0 mm	Boring Bar 1.259" x 1.378"			350	970	.004	3.88	1.64	0.46
	Dias	Dias 1 T.C. Blade each								
	Index 180°									0.20
	Finish dia. 32.0 mm other end								1.15	0.35
6	Bore-Finish 40.3 mm dia.	Boring Bar 1.588" 1 T.C. Blade			350	840	.005	4.2	1.76	0.45
7	Drill and co'sink 2 holes	Step drill 6.8 mm (0.267")			70	1000	.005	5.0	0.85	0.40
	Position 1 Time	and co'sink								0.06
8	Tap 2 Holes M 8 x 1.25	Tap M 8 x 1.25			30	360		17.71	.73"	0.20
	Position 1 Time									0.06
	Index 90°									0.15
9	Drill 6 Holes 9 mm dia.	T.C. Drill 9 mm dia (0.359")			180	1915	.0065	12.4	2.0"	1.20
	Position 5 Times									0.30
	9-Tool Changes									3.60
PROCESS ENGR.									TOTAL TIME	10.53

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PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Gear Change Cover	1246-306-068
		MATERIAL Cast Iron	RELEASE SHEET 1 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture - First and Second Setups in Same Fixture									
1	Mill Face	Shell End Mill 5.0" dia.			250	190	.180	15.2	11.0"	0.75
		10 T.C. Blades								
2	Drill 6 Holes 9 mm dia.	T.C. Drill 9 mm dia (0.359")			180	1915	.0065	12.4	.80"	0.60
	Position 5 Times									0.30
	Index 90°									0.20
3	Spot Drill for 5 mm dia hole	Spot Drill 0.50 dia H.S.S.				1300	.006	7.8	.25	0.12
4	Drill 1 5 mm dia. hole	T.C. Drill 0.197" dia.				2500	.004	10.0	.65	0.15
	Index to fixture station 2									0.20
5	Hollow Mill 9 mm dia & chamfer	Hollow Mill 3.543 dia & chamfer			250	270	.010	2.7	1.4"	0.55
		2 T.C. Blades each								
	Index 90°									0.20
PROCESS ENGR.		TOTAL TIME								

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PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Gear Change Cover	1246-306-068
		MATERIAL Cast Iron	RELEASE SHEET 2 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
6	Drill 2 Holes 12 mm dia.	Drill/Bore Tool 0.4724 dia. T.C.			170	1375	.008	11.0	.86"	0.10
	Index 180^{o}									0.20
	Feed Other Side								.86	0.10
	Index 90^{o}									0.20
7	Bore and chamfer 80 mm dia.	Boring Bar 3.15" dia. and 30^{o}			250	306	.006	1.83	.87	0.50
		chamfer - 1 T.C. Blade each								
	Index to Exit									0.20
	7-Tool Changes									2.80
PROCESS ENGR.									TOTAL TIME	7.17

JN 81/40

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Bell Cover	1246-301-032 and 1290-301-065
		MATERIAL Cast Iron	RELEASE SHEET 1 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Fixture Same for Both parts 1 Part in Fixture									
1	Spot Drill 2 Places	Spot Drill 0.50 dia.				660	.008	5.28	.30"	0.14
	Position 1 Time									0.08
	Index 180°									0.20
	Repeat 2 Places									0.22
2	Drill (2) Holes (rough)	T.C. Drill 0.937 dia.			160	650	.013	8.45	2.58"	0.68
	Position 1 Time									0.08
	Index 180°									0.20
	Repeat 2 Holes									0.76
3	Bore Semi-Finish 2 Holes	Boring Bar 0.990" dia. 1 T.C.			350	1350	.004	5.40	2.3"	0.90
	Position 1 Time	Blade								0.08
	Index 180°									0.20
	Repeat 2 Holes									0.98
PROCESS ENGR.								TOTAL TIME		

JN 81/40

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Bell Cover	1246-301-032 and 1290-301-065
		MATERIAL: Cast Iron	RELEASE SHEET 2 OF 2

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
4	Finish Ream 2 Holes	T.C. Reamer 1.006" dia.			120	455	.024	10.92	2.4"	0.48
	Position 1 Time									0.08
	Index 180°									0.20
	Repeat 2 Holes									0.56
	4-Tool Changes									0.60
PROCESS ENGR.									TOTAL TIME	7.44

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EXAMPLE PROPOSAL FOR AN FMS TO MACHINE PRISMATIC PARTS

PROPOSAL NO. A430-8999 DATE 1/31/81

Oper No	MACHINE DESCRIPTION	PART NAME	PART No
	MODEL 007	Main Housing	1246-301-037
		MATERIAL: Cast Iron	RELEASE SHEET 1 OF 1

SEQ. No.	OPERATION DESCRIPTION	TOOL & EQUIPMENT DESCRIPTION	TOOL No.	H.P. REQ'D	SFM	RPM	IPR	IPM	FEED LENGTH	EST. MINUTES
	Mill Rear Pad, Drill and Tap for PTO 1 Part in Fixture									
1	Rough Mill Pad	End Mill 3.0" dia 6 T.C. blades			250	320	.036	11.5	15.5"	1.35
2	Finish Mill Pad	6.0" Shell End Mill 12 T.C. T.			350	220	.072	23.76	13.75	0.60
3	Drill 4 Holes and co'sink	Step Drill 0.344" dia & co'sink			70	775	.007	5.4	.84	0.72
	Position 3 Times									0.18
4	Tap M 10 x 1.5 4 Holes	Tap m 10 x 1.5			30	290		17.11	.76	0.44
	Position 3 Times									0.18
	4-Tool Changes									1.60
PROCESS ENGR.								TOTAL TIME		5.07

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2.11 PRICING, DELIVERIES, TERMS, AND CONDITIONS

2.11.1 Progress Payments

The Contract Price and subsequent Amendments are subject to Progress Payments. The payment schedule is expressed as a percentage of the total sales order.

Progress Payment	Time of Payment
10%	With order.
30%	At start of assembly.
50%	Upon shipment of eqiupment, net 30 days.
10%	Upon acceptance, the equipment supplied in each separate phase, but not to exceed 90 days from date of shipment.

2.11.2 Pricing and Deliveries

The flexible manufacturing, system, as described in the foregoing sections, including the following specific equipment:

1. (6) Model 007 Machining Centers as described, including:

   Model 007 Computer Numerical Control.

   360-degree rotary index work module with special pallet deliver/discharge unit to interface with the automatic material transport system (including entrance and exit queue space for pallets).

   Compute coolant system, flood and mist (no jet pulse).

   Random tool selection, shortest path.

   Automatic air blow-off during tool interchange.

   SCR electric servo drive for axis travel.

   20 to 3300 RPM spindle speed range.

   Automatic lubrication system.

Diagnostics package for machine and control.

For description of all standard features, consult the proposal letter and catalogues.

Price for Each Machine: $487,100.00
Price for Six Machines: $2,922,600.00

- In addition to the features listed above, we offer the following options at extra cost:

  Additional 30-tool-chain matrix (increases storage capacity to 60).

  Price per Machine: $35,900.00

  Through spindle coolant system jet pulse, includes chip and coolant shield.

  Price per Machine: $25,542.00

  Special leaf-type chip conveyor for FMS application.

  Price per Machine: $17,365.00

  Refrigerant-cooled heat exchanger (replaces standard water-cooled type).

  Price per Machine: $4,200.00

  Precision surface sensing probe (includes 24 fixture offsets).

  Price per Machine: $10,000.00

  One set of 8 auxiliary miscellaneous (M) functions.

  Price per Machine: $800.00

2. Documentation.

   Documentation relating the Model 007 Machining Center includes two sets of the following:

   Instruction Manual for Machine and Control

   Service Manual

   Parts Manual

   Basic Part Programming Guide

   Service Manual CNC Console

3. (1) Automatic material handling system including the following:

(3) Battery-powered, wire-guided carts, with chip and coolant guards, fine positioning, and high traction tires (without batteries).

(2) Manual cart controls.

(9) Sets of batteries (one set per vehicle per shift).

(3) Battery chargers.

(1) Frequency generator.

Necessary area controllers.

Necessary battery carts.

Recommended spares for wire-guided carts.

Recommended spares for area controllers and frequency generator.

Field installation, including cutting of floor wiring, stop plates, cones, and engineering supervision.

Price: $468,520.00

- In addition to the above, we offer the following options at extra cost:

  (1) Spare battery-powered, wire-guided cart.

  Price: $61,360.00

  (1) Set of batteries

  Price: $4,730.00

4. FMS Control System including the following:

<u>Central Computer Hardware (PDP-11/44)</u>

(1) SM40UAA-CA PDP-11/44 Computer System:
With: 128K words of MOS memory
(1) 67MB Disk Drive
(1) TS11 Tape Drive (1600 BPI only)
(1) LA120 1200 Baud Console
(1) QJ629-CD RSX-11M/Plus Operating System

(1) MS11-MB 128K Words additional MOS Memory
(4) DD11-DK Backplanes
(1) H9642-DB Expansion Cabinet
(1) BA11-KW Expansion Box for Backplanes
(1) DZ11-A Connects for 6 Machines
(1) DZ11-E Connects for 6 CRTs and Traffic
(15) BC03M-25 Cables at $65.00 each

(2) KMC11-A Auxiliary Processors for DECNET
(1) KG11-A Hardware CNC Unit (DECNET)
(6) VT100-AA CRTs
(1) LP11-VA 300 LPM Printer or...
(1) LP11-AA 285 LPM Band Printer
(1) Remex Paper Tape Reader/Punch and Controller

<u>Central Computer Software:</u>

(1) QJ629-CD RSX-11M/Plus Operating System
(1) QR580-AD DECNET-11M/Plus
(1) QJ668-AD FORTRAN IV Plus Compiler

<u>Cart Control Computer</u>

<u>Computer Hardware (PDP-11/24):</u>

(1) PDP-11/24 Computer System:
With: 128K words of MOS Memory
(1) H9642 Expansion Cabinet
(1) DZ11-C 20 ma connect
(1) DD11-CK Backplane
(1) DL11-WB
(1) DL11-E
(1) KG11-A Hardware CRC Unit (DECNET)
(1) 9301-YE Boot Board
(1) VT100-AA CRT or...
(1) LA120 120 Baud Console

<u>Computer Software</u>

(1) QJ642-DZ RSX-11S Operating System
(1) QJ694-DZ DECNET-11S

Price: $336,410.00

- In addition to the above, we offer the following options at extra cost:

  <u>Hardware/Software for RJE Capability</u>

  (1) DU11-DA 2780 Interface Board
  (1) KG11-A Hardware CRC Unit (2780)
  (1) QJD68-DZ RSX-11M/2780 Software
  (1) VM/RJE Software Package

  Price: $7,375.00

  <u>Hardware/Software for UCC APT Capability</u>

  (2) MS11-MB 128K Words additional MOS Memory (Total 257K Words)
  (1) RM02-AA 67MB Disk Drive
  (1) UCC APT Compiler

(1) UCC 3-Axis Post-processor

Price: $77,625.00

Note: Both options may require that additional hardware be purchased to complete installation.

5. (1) Environmentally-controlled computer room installed at your plant.

   Price: $27,500.00

6. (7) Load Stations - (6) with capability to communicate with the FMS computer.

   Price: $124,335.00

7. (21) Pallets 32 inch square complete with identification components

   Price: $94,500.00

8. Project engineering (project coordination at our facility).

   Price: $26,400.00

9. On-Site project engineering and supervision.

   Price: $119,625.00

10. The following prices are approximate only:

   - Upon completion of all tool and fixture layout drawings and approval by your tooling people, final firm prices for both durable and perishable tooling will be given in a supplemental quote.

     The approximate price quoted below is based on a careful study of the application:

     (21) Fixtures - Manual Clamping

     (8) Cover (1246-301-032 & 065)
     (1) Main Housing (1246-301-037)
     (4) Tower (1246-301-068)
     (4) Housing (1290-307-001)
     (1) Cover (1246-301-035)
     (2) Retainer (1290-302-101 & 072)
     (1) Retainer (1246-307-110)

     Approximate Price: $296,400.00

- (6) Sets of Durable Tooling to Machine Parts Listed in Letter Portion of Quote (one set per machine).

  Approximate Price: $76,800.00

- (6) Sets of Perishable Tools (one set per machine).

  Approximate Price: $54,900.00

- Tool Layouts for Above-Listed Tooling.

  Approximate Price: $20,100.00

- Part Programming for Parts listed in Letter Portion of Quote.

  Approximate Price: $35,540.00

- Part Runoff (this price is based on running three different parts on each of the first three machines. A total of ten pieces of each part will be machined.)

  Approximate Price: $69,350.00

<u>Price Summary</u>

(6) Model 007 Machines
(1) Automatic Material Handing
(1) FMS Control System
(1) Computer Room
(7) Load Stations
(21) Pallets
(1) Project Engineering
(1) On-Site Supervision
(21) Fixtures
(6) Sets Durable Tools
(6) Sets Perishable Tools
(1) Tool Layout
(1) Part Programming (9 parts)
(1) Part Runoff

Total Price (less options): $4,672,980.00

<u>Note:</u> Prices as quoted are for delivery in the continental United States; prices will be adjusted for other destinations.

2.11.3 Shipping Schedule

Shipment of the proposed machines and equipment can be made per the following schedule. This dates from the receipt of your formal order and complete information in our facility. These shipment schedules are quoted subject to prior sale.

First	Model 007 and Material Handling System	78 weeks
Second	Model 007	80 weeks
Third	Model 007	82 weeks
Fourth	Model 007	82 weeks
Fifth	Model 007	82 weeks
Sixth	Model 007	84 weeks

2.11.4 Proposal Number and Terms and Conditions

This quotation, including the printed terms and conditions which follow, comprises our complete proposal. The processing of your order will be facilitated if you will indicate on its face the reference phrase, "In accordance with your Proposal No. A-430-8999-R1", dated March 16, 1981".

Proposal concluded at attached Form JN-74-112.

Section I, paragraph (e) on attached "Terms and Conditions" does not apply.

Any order or group of orders resulting from this proposal is subject to payment terms as outlined in the enclosed attachment, Form No. JN-79/06, entitled "Standard Payment Terms".

This proposal and any resultant contract are not assignable without our prior written consent.

Prices contained in this proposal shall remain in effect until June 20, 1981. After this date, price and delivery are subject to review.

2.11.5 Termination Liability Schedule

The following termination liability schedule must be included in the purchase order and becomes effective upon receipt of the purchase order or authority to proceed at our facility. It is expressed in months and percentage of the total sales order.

In the event of termination of all or any part of the contract at any point throughout the scheduled months of the contract and termination charges be less than the "Progress Payments" made at that time, the difference would be refunded to the customer.

Month After Receipt of Formal Order or Authority to Proceed	Liability Percentage of the Sales Order
1	2%
2	5%
3	7%
4	12%
5	18%
6	24%
7	30%
8	36%
9	42%
10	48%
11	54%
12	60%
13	66%
14	72%
15	78%
16	84%
17	90%
18	96%
19	100%
20	100%
21	100%

2.11.6 System Warranty Statement

This flexible manufacturing system is designed with certain assumptions in order to produce the buyer's parts in a ratio commensurate with the daily production requirement, provided that part lot sizes are introduced in quantities of three times the daily requirements. It is important to note that a production frame of less than three times the daily requirement may result in somewhat less system utilization and production throughput. A larger production frame may result in a better system utilization and production throughput. A production frame, then, is defined as a mix of parts that are introduced to the system as a group in a set ratio. No additional parts are introduced to the system until <u>all</u> parts in the production frame are finished.

Based on a production frame size which is equal to three times the daily requirements for the nine parts, the daily production will be as follows:

Part Number	Description	Amount (Daily)
1246-301-032	Bell Cover	101
1246-301-035	P.T.O. Cover	15
1246-301-037	Main Housing	15
1246-301-065	Bell Cover	168
1290-302-101	Bearing Retainers	84
1290-302-072	Bearing Retainers	84
1246-307-110	Bearing Retainers	101
1246-301-068	Shift Tower	161
1290-307-001	Control Housing	108

There are many factors which effect the total production that will be achieved from this flexible manufacturing system.

We do not guarantee the above daily production rates since the operation and management of this system is not within our control.

This quantity of machine tools, material handling devices, load stations, etc., as set forth in this proposal are configured based on an assumed production efficiency that can be achieved by the buyer. The actual production efficiencies achieved may vary depending on the buyer's manufacturing practices. Additional equipment requirements to meet production rates is at the expense of the buyer.

In addition to the warranty and terms stated on the attached form JN-74-112, we guarantee the following:

1. The parts listed above can be produced and made to accuracies as agreed by us and the buyer as stated within this proposal, by the machine tool equipment supplied.

2. The time required to machine the parts at each machine station is within the specified time cycle as stated within this proposal. The time cycle includes:

    a. The time necessary to shuttle the part from the machine station input queue to the work station queue.

    b. All tool-change times.

    c. All machine-axis positioning times.

    d. All metal removal times specified by using the feed rates and spindle speeds selected by us.

Items not guaranteed by us are as follows:

1. Part load and unload times. The buyer's personnel have total control of the time required to load and unload parts from the fixtures. Aids to assist the load station operators such as cranes, lifts, power, etc., are the responsibility of the buyer.

2. System production. The quantity of parts produced within the system during a specific period of time is dependent on factors totally controlled the buyer and not guaranteed by us. These factors include, but are not limited to:

   a. Machine Maintenance. The time required to repair breakdowns. Dependent upon the quality and availability of service personnel and spare parts.

   b. Spare Parts. The buyer has a responsibility to stock a sufficient quantity of spare parts so that equipment downtime is minimized.

   c. Tool Service. This nonproductive time is required to change tool setups when entering new parts into the system, as well as replacing worn or broken tools. Adjustments of boring bars, cutter inserts, etc., fall within this category.

   d. Parts availability.

   e. Operations personnel availability.

   f. Chip Removal. Interruptions to machining operations for chip removal.

   g. Fluid Change. Interruptions to machining operations for coolant and oil changes.

   h. Feed-rate and spindle-speed overrides.

   i. Part Program Changes.

   j. Preventative Maintenance. This necessary time is required to assure the best perforamnce of the equipment. The time and frequency of preventative maintenance is the control of the buyer.

   k. Chip Problems. Delays in the machining process necessitated to remove chips from parts and tools.

   l. Material Variations. The part material exceeds the physical and metallurgical specifications of the part.

   m. Quality Control. Time delays required to inspect parts while they are at the machining stations.

3. Tool Life. Cutting tool life is a function of speeds and feeds as well as the quality of the tool. The buyer's manufacturing practices greatly influence tool life. The parts' time cycles as stated within this proposal are based on the speeds and feeds selected by us and based on good machining practices and past experience with the material being machined. Alterations of these feeds are at the risk of the buyer.

4. Operations Manpower. The quantity of load stations operators, tool setters, trouble-shooters, management personnel, etc., required for this system is very dependent on the buyer's experience with systems,

quality of personnel, labor contracts, etc. We can only suggest a level of operations personnel required to meet the production rates. The actual quantity of people required may vary, depending on the buyer's method of operations.

2.11.7 Occupational Safety and Health Act of 1970 as Related to FMS Equipment

We, the vendor, hereby state to the best of our knowledge and belief, the equipment as delivered, complies or comply with those sections of the Occupational Safety and Health Act of 1970, as amended ("OSHA", Code of Federal Regulations, Title 29, Chapter XVII), which provides standards for such items as occupational noise exposure; electrical circuits; warning plates; paint colors; environmental conditions; and guarding of belts, pulleys, gears, chains, and sprockets.

Because of the general purpose nature of the equipment and wide variety of parts which can be machined, the vendor does assume responsibility for supply of "Point of Operation" guarding. This will be the customer's responsibility.

In order to help the user meet the requirements of the Act as they apply to this equipment, we have incorporated features which to the best of our knowledge and belief would satisfy the requirements of an Occupation Safety and Health Administration Compliance Officer upon inspection.

Due to the general and therefore subjective nature of some of the OSHA regulations, the vendor does not certify that all third persons necessarily will concur with its statement of compliance.

The following features are hereby included as part of the basic machine tool to help the user in an effort to comply with the Act.

1. Electrical interlock switches, and/or electrical circuit breakers are on the inside of hinged doors to stop operation whenever the door is opened.

2. Emergency stop buttons will be mounted at the operator's normal positon or positions.

3. Appropriate warning plates will be provided and mounted. After installation, additional marking may be necessary as dictated by on-site conditions; this additional marking would be the user's responsibility.

4. Painting will be as follows: Inside the electrical compartment shall be painted white; inside the hinged doors shall be painted orange; inside of the belt guard shall be painted orange; face of driver, driven, and idler pulleys shall be painted orange. All stop buttons will be red. Pinch points on the equipment will be painted yellow.

5. All equipment will have adequate guarding for belts, pulleys, gears, chains, and sprockets.

6. Where high voltage exists (over 50 volts), the vendor will provide his equipment with guarding to help ensure operator safety.

7. Noise level will not exceed 90 dBA, unless a lower level is specified and agreed upon. Measurements are made according to "NMTBA Noise Measurements Techniques", dated January 1976 and published by National Machine Tool Builders Association, 7901 Westpart Drive, McLean, Virginia 22101.

8. We believe it to be the user's responsibility to provide proper smoke removal equipment, fire extinguishing equipment, and to keep the surrounding environmental conditions safe for the operator.

9. In the battery charge area, an eye-wash basin and whatever else is required to meet OSHA regulations will be the responsibility of the user.

10. New guarding for the machine and equipment will be required. It will be the user's responsibility to design and manufacture "on-site" this guarding.

11. We feel that the equipment supplied as outlined above, and with the user taking the necessary precautions, would meet with the approval of the inspecting officer.

2.12 CUSTOMER'S RESPONSIBILITY

2.12.1 Customer Participation

It shall be the duty of the customer to lend their best efforts and cooperate fully with the vendor to meet the performance schedule as spelled out on the Project Time Frame Chart shown in a previous section. Following is a listing of areas of responsibilities, but is not necessarily all inclusive.

2.12.2 Foundations

The customer will provide all machine foundations to meet the project schedule delivery dates.

This includes masonry work, electrical, water and air service at each machine site, computer room and battery-charging area. This also includes the eye-wash area and necessary equipment to meet OSHA regulations at the battery-charging area.

2.12.3 Part Inspection

The customer will provide inspection facilities, jigs, any special gauges, etc., to allow for tape proveout at our facility.

2.12.4 Coolant Guards and Chip Control

The customer is responsible for any coolant or chip guards they deem necessary for operation control. If the customer is going to install future coolant or chip systems, the customer will have to incorporate those plans into the foundation.

2.12.5 Personnel

The customer must provide responsible and capable personnel for training by us.

2.12.6 Castings

1. We require one casting of each part number as soon as it can be sent, for process planning.

2. We require ten castings of each part number to be processed. The above items must be received by us at a reasonable date or a project delay will result. Additional castings may be required. We will not be charged for castings scrapped during tape proveout.

2.12.7 Customer Support for Acceptance Tests

During the acceptance tests at the customer's plant, we will require the customer's support in functions such as tool setting and maintenance, inspection and possibly machine operation.

2.12.8 Miscellaneous Equipment

1. Cleaning or deburring units.

2. Central chip removal or chip removal equipment.

2.13 MACHINE ACCEPTANCE

Included in the system price will be a simulated production run at our plant of ten parts of each type for which tooling and programming are purchased.

We propose to run three different parts on each of the first three machines to prove out the machine, tooling, programming, and cycles times.

The fourth, fifth, and sixth machines will be demonstrated at our plant by performing standard test cuts, plus demonstration of the delivery/discharge equipment.

This will serve as a preliminary verification of cycle time and quality capability of the equipment.

The buyer is to supply any special gauges or equipment required for the checking the parts. We will provide standard type inspection equipment, micrometer height gauges, the use of a coordinate measuring machine, etc.

We will machine the parts to the tolerances as outlined in the buyer's part drawings per the following list:

Part Name	Part Number	Date	Print Name
Retainer	1290-302-101	9-15-80	Connection Plate
Retainer	1290-302-072	9-15-80	Connection Plate
Retainer	1246-307-110	8-12-80	Connection Plate
Cover	1246-301-035	9-12-80	---
Housing	1290-307-001	8-12-80	Gear Change Cover
Tower	1246-301-068	8-12-80	Gear Change Cover
Bell Cover	1246-301-032	9-12-80	Bell Housing
Bell Cover	1246-301-065	9-15-80	Housing Clutch
Main Housing	1246-301-037	8-11-80	Housing

Part Numbers 1290-302-101, 1290-302-072, and 1246-302-110 are to be roughed off-line.

At the buyer's plant, we will, at your request, run ten of any one part on each machine to verify cycle time and tolerance capability.

If this is considered unnecessary, we will proceed directly to a one-day production run with one batch of parts entered into the system in the following amounts.

Part Number	Description	Amount (Daily)
1246-301-032	Bell Cover	101
1246-301-035	P.T.O. Cover	15
1246-301-037	Main Housing	15
1246-301-065	Bell Cover	168
1290-302-101	Bearing Retainers	84
1290-302-072	Bearing Retainers	84
1246-307-110	Bearing Retainers	101
1246-306-068	Shift Tower	161
1290-307-001	Control Housing	108

The above production will be made in twenty-four hours or less (65% estimated efficiency).

This production is contingent upon the system being kept fully loaded at all times. If, for any reason, other than FMS system failure, the system is not kept fully loaded, then that period of time shall be added to the twenty-four hour time period.

Part tolerance verification shall be the buyer's responsibility. The data shall be supplied to us, and we will take corrective action if required.

Provided that the system meets the production requirements and the parts are within print tolerance, then the system will be considered to be accepted.

In the event that sufficient parts are unavaiable when the system is ready for demonstration, the acceptance shall be based on a demonstration of the system capability by running fixture/pallet combinations through the system without parts (dry run).

3.0 FMS PART/MACHINE SELECTION CASE STUDY: ROCK ISLAND ARSENAL

3.1 EXAMPLE CASE STUDY

An example of many of the steps required in part/machine selection is provided by the Rock Island Arsenal, Rock Island, Illinois, preliminary FMS feasibility case study. This section recounts details of that example.

3.1.1 Description

Rock Island Arsenal is a batch-type, metal parts manufacturing facility. The Arsenal uses 2,000 machine tools including 50 NC machines and employs a labor force of 650 workers for metal fabrication processes. The primary purpose of Rock Island Arsenal is to provide industry with sufficient lead time, if war is declared, to tool up their facilities for production of various armament parts. The required lead time is about 200 days.

In wartime, Rock Island would manufacture twenty-one mobilization end items. In peacetime, there are only nine end items. Thus, many Rock Island machines are idle in peacetime, although work is spread out to utilize and maintain them.

The net result of peacetime machine use is the exaggerated movement of parts to the far corners of the Arsenal. The average part travels two and one-half miles in fifteen moves. The objective of project REARM is to consolidate the facility into a smaller area and to reorganize the shop floor plans to expedite part handling.

3.2 WORK CONTENT DISTRIBUTION STUDY

The end items produced at Rock Island in peacetime include gun mounts, recoil mechanisms, machine guns, towed artillery, and spare parts with monthly rates in the 1 to 106 range, though most of the items fall in the 10 to 20 per month range. There are a large number of parts, a total of 3,338 active part numbers to be manufactured.

Before a Group Technology classification and coding system was installed at the Arsenal, routing files alone were used to select parts for possible manufacture on an FMS. The routing of each of these parts and the manufacturing processes involved are contained in computer files. Figure 4 on page 124 illustrates the information available in the computer file.

The FMS-compatible processes include milling, boring, drilling, tapping, and some turning of disk-shaped parts. These operations, according to Rock Island Arsenal's Machine Group Listing (a sample of the Machine Group

ROUTING FILE GIVES IMPORTANT PARAMETERS NEEDED FOR PART SELECTION

CARD TYPE	COMP REQD	SCRAP FACT	EXPENDITURE ORDER	JOB ORDER	PART NO.	MFG CODE	CMI	SETUP HRS.	HRS. PER PC	MM	PROC CODE	MACH. GROUP	T/S	OPER NUM.	COST CTR	D C
1	105	1.05	11704	0011017	7790871		000	3.5	0.0240	1	0	4750	A	10	6710	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0000	1	0	0		15	5183	P
1	105	1.05	11704	0011017	7790871		000	2.0	0.0270	1	0	2035	A	20	7040	P
1	105	1.05	11704	0011017	7790871		000	1.8	0.0200	1	0	2045	A	30	7040	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0000	1	0	0		35	5157	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0410	1	18	8610	A	40	7831	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0410	1	19	8610	A	50	7831	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0410	1	19	8610	A	60	7831	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0000	1	0	0		65	5133	P
1	105	1.05	11704	0011017	7790871		000	4.0	[illegible]	1	0	5160	A	70	7090	P
1	105	1.05	11704	0011017	7790871		000	1.0	0.0520	1	0	5160	A	80	7090	P
1	105	1.05	11704	0011017	7790871		000	2.0	0.0220	1	0	5360	A	90	7090	P
1	105	1.05	11704	0011017	7790871		000	2.0	0.0390	1	0	5440	A	100	7090	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0000	1	0	0		105	5158	P
1	105	1.05	11704	0011017	7790871		000	0.3	0.0170	1	0	9999	A	110	7110	P
1	105	1.05	11704	0011017	7790871		000	0.0	0.0000	1	0	0		115	5159	P
1	105	1.05	11704	0011017	7790871		000	1.8	0.0190	1	0	2030	A	120	7040	P

SCRAP FACTOR

END ITEM NO. (EXPENDITURE ORDER NO.)

PART NUMBER

SETUP TIMES (HRS)

MACHINE TIMES (HRS/PCS)

MACHINE GROUP CODE

OPERATION NUMBER

COST CENTER CODE

Figure 4. Sample Process Routing File (Rock Island Arsenal)

Listing is presented in Figure 5 on page 126, are covered by Machine Group Codes 2000 to 3999. Specifically, they include the following:

2010-2224 Milling machines

2241-2290 Milling machines

2420-2730 Horizontal boring mills, vertical turret lathes (VTLs) vertical boring mills, and jig borers.

2750 Special planers for M178 cradle

2820-3260 Vertical shapers, drills

If the process routing files indicated that a part was processed on these types of machines, it was an initial FMS candidate. If the part was processed by any of these machine groups and then by some other group, it was assumed to exit the FMS. If the reverse was true, it was assumed to enter the FMS. The total number of entries and exits from the FMS were counted from the process routing files. If they were numerous (three or more), the part was assumed not to be compatible with an FMS. Also, the total time spent on the FMS-compatible machines is accumulated to identify a maximum possible FMS work content.

Additionally, analysis of the part work content distribution was made to distinguish work suitable to prismatic FMSs and work suitable for rotary FMSs. The purpose of this study was to give an assessment of the relative significance of various types of machining systems (i.e., rotary or prismatic FMSs).

The results of the study are summarized in Figure 6 on page 127. As illustrated in the table, there is impressive work content intensity for FMS-compatible machining operations. The prismatic FMS-compatible work content ranges from 38.53% to 61.76% of the overall machining work content for the nine expenditure orders. Likewise, the rotary FMS-compatible work content ranges from 26.93% to 59.33% of the overall machining work content. Primarily because the state-of-the-art for prismatic FMSs is ahead of that for rotary FMSs, the remainder of the study concentrated on prismatic parts.

3.3 MACHINE CLASSES

After viewing the Arsenal machines in operation and discussing them with the Arsenal personnel, the list of the FMS-compatible machine groups was finalized. Overall, 109 machine groups were listed as FMS-compatible, mainly in the categories of the milling, drilling, boring, and other hole-making operations, with two main exceptions. First, all deep-hole

Machine Group	Brief Machine Group Description
2540	Bullard, Vcl, Tbl 36"
2560	Bullard, Vcl, Tbl 42"
2565	Bullard, Vcl, Tbl 46"
2570	Bore Mill, Vert, Tbl 54"
2590	Bullard, Vcl, Tbl 64"
2600	Bore Mill, Vert, 7'
2610	Bore Mill, Vert, 10'
2620	Bore Mill, Vert, 12'
2680	Bore Mch
2700	Mill, Omni, Vert
2710	Jig Bore, Hor, NC, 4"
2715	Dvlg Jig Bore, Hor, NC, 4"
2720	Jig Bore, Vert
2722	Jig Bore, NC
2725	Bore Mch
2730	Jig Bore, Vert
2740	Planer, Str 12', W 4'
2750	Planer, Str 18', W 4'
2760	Planer, Str 40', W 5-1/2'
2770	Shaper, Str 24', W 14"
2780	Shaper, Str 66", W 24"
2790	Slotter
2820	Shaper, Vert, Str 12", 24" D
3010	Drill, Bench, 0-2MT
3020	Drill, Flr, 1 Spdl, 1-2 MT
3021	Sgl Pur Drill
3023	Drill, 20 MM
3030	Drill, 2 Spdl, 1-2 MT

DETAILED CLASSIFICATION OF ROCK ISLAND ARSENAL MACHINE TOOLS INTO MACHINE GROUPS (MG).

2715 DEVLIEG JIG BORE HOR, NC, 4"

Figure 5. Partial Machine Group Listing (Rock Island Arsenal)

Expenditure Order	Prismatic FMS-Compatible			Rotary FMS-Compatible	
	Overall Part Nos.	Part Nos.	Work Content (% of overall machining work content)	Part Nos.	Work Content (% of overall machining work content)
M140 Gun Mount (12709)	84	33	38.53	50	52.49
M85 Machine Gun (90031)	235	90	61.76	151	26.93
M174 Gun Mount (12801)	459	171	39.13	255	53.38
M178 Gun Mount (12802)	247	92	45.25	121	43.57
M101A1 Howitzer (108)	696	238	56.42	307	54.15
AVL B Bridge Launcher (920000)	281	115	48.21	115	53.36
M45 Recoil Mechanism (930000)	222	84	41.79	137	47.86
M8C Spotting Rifle (11704)	94	38	50.28	69	32.48
M39 Carriage (910000)	1020	396	58.82	309	59.33

Figure 6. Work Content Distribution

drills were eliminated because all of these were gun drills wherein the work, not the drill, rotates. Secondly, most planers were eliminated because they are used for very long parts. Figure 7 summarizes the list of Rock Island FMS-compatible machine groups.

Machine Group	Machine Tool Type
2010-2224 2241-2290, 2700	Milling Machines
2420-2520, 2680	Horizontal Boring Mills
2531-2620	Vertical Turret Lathes, Vertical Boring Mills
2710-2730	Jig Borers
2750	Special Planer for M178 Cradle
2820	Vertical Shaper
3010-3260	Drilling Machines

Figure 7. Rock Island FMS-Compatible Machine Groups

In addition, the classes of machines for the proposed FMS were defined. Four classes with ten models were selected. They were machining centers of small, medium, and large size; precision boring modules of small, medium and large size; multiple-spindle modules of medium and large size; and vertical turret lathes of medium and large size. A machine replacement matrix was implemented to map each of the 109 machine groups into a corresponding FMS machine model according to their envelope size, accuracy specification, and power rating. The detailed machine replacement criteria and the machine replacement matrix are presented in Figure 8 on page 129 and Figure 9 on page 130, respectively.

Milling Machines, Jig-Boring Machines

Small:	< 30" X or < 12" Y Travel
Medium:	< 50" X or < 18" Y Travel
Large:	All others.

Drills

Small:	< 16" diameter or 16" Y Travel
Medium:	< 48" diameter or 48" Y Travel
Large:	All others.

Vertical Turret Lathes, Vertical Boring Machines

Medium:	< 50" diameter table
Large:	> 50" diameter table

Multiple-Spindle Drills

Medium:	No. 1 Morse Taper Spindle
Large:	All others.

Figure 8. Machine Group Replacement Criteria

Type	Small	Medium	Large
Machining Center	2010-2040, 2070, 2100,2110, 2150-2160, 2270-2290, 2700, 2820,3010, 3040,3050, 3060,3118	2045-2060, 2105, 2165-2180, 2190, 2220, 2241-2242, 3020,3030, 3055, 3065-3080, 3100, 3112,3113, 3116, 3180-3200	2090,2140, 2185, 2188, 2196-2210, 2222-2224, 2245-2261, 2420-2520, 2750, 3095,3105, 3115, 3120-3160
Precision Boring	2720	2730 2725	2710,2715,
Multi-Spindle		3220,3221, 3240	3230,3250, 3260
Vertical		2533, 2540-2567	2531,2535, 2570-2620

Figure 9. Machine Tool Replacement Matrix

3.4 PART DATA MODIFICATION

A conservative approach was taken for the modification of the part processing data, compared to the "rules-of-thumb" discussed in Volume III. Specifically, the machining times were not decreased due to the use of an FMS rather than stand-alone manual and NC machines. Also, instead of assuming two setups (fixturings) for each part at a total of eight minutes each, an attempt was made to estimate the actual number and duration of the FMS fixturings for each part, as described below.

First, to improve the estimate of work content, a fixturing time reduction algorithm was devised. It recognizes the different approaches to fixturing used for stand-alone machines as compared to FMSs. For example, the algorithm assumes some existing setups can be combined if the part is made on an FMS. In developing this algorithm, part size became a factor. The part was sized according to the size of the milling machine or drill on which it was machined. Machines were as classed small, medium, or large, according to table travel, drill throat, or table diameter (VTL, etc.). These size constraints were used to categorize the probable fixture design for the FMS. In particular, if a part was ever machined on a small milling or drilling machine, it is assumed compatible with picture-frame fixturing which yields access to at least four sides of the part for machining. However, large parts were considered to be too cumbersome for this arrangement in general.

Fixturing times from the candidate routing files were eliminated for the FMS for:

1. Drilling operations following milling operations.

2. Sequential milling operations for medium-sized parts. If the part was small, the longest fixturing time was chosen if the mill and drill operations were in a loop.[1]

3. The shorter of two boring fixturing times in a loop, and all but the two longest if there were more than two boring fixturings.

4. The boring fixturing if there was only one boring operation and the part was milled.

Second, if a part left the FMS machine groups and then returned, the fixturing time algorithm again was exercised.

For each FMS entry loop:

1. Check part size by identifying smallest machining category of mill and drill.

    a. If small category is found, choose largest fixturing time of mill or drill fixturing in this loop.

---

[1] A loop is defined as the sequence of operations on FMS-compatible machines.

b. If not small, eliminate fixturing times of any drilling operations following milling. Also, eliminate sequential milling fixturing times for medium-sized parts.

2. Retain all fixturing times for VTL operations.

3. If jig boring:

   a. is performed only once, and the part also is milled; eliminate the jig boring fixturing.

   b. is performed twice; eliminate the smaller fixturing time.

   c. is performed more than twice; retain the two longest fixturing times.

3.5 RESULTS OF PART/MACHINE SELECTION

The data on parts and machines were processed using the software package PAMS (see Volume V) a number of times with different constraints on the number of FMS machines. Example outputs are shown in Figure 10 on page 133.

This case study illustrates that minimal part and machine data are required in order to use PAMS to determine whether FMS technology might be economical. From the economic output -- payback period, for example -- it can be decided to continue examination of the parts, or to conclude the feasibility study. As illustrated, PAMS indicated that FMS technology has the potential for successful application to Rock Island Arsenal manufacturing. Based on this information, the decision was made to continue with a more detailed study.

No. of Machines in FMS	Machine Class				No. of Parts Selected	Cost Savings ($k/yr)	Total Cost of System ($k)	Pay Back Period (years)
	Machining Center			Vertical Turret Lathe				
	small	medium	large					
20	5	7	7	1	229	3960	12,400	3.14
10	2	2	5	1	93	2532	7400	2.92
8	1	1	5	1	80	2136	6600	3.08
5	0	0	4	1	57	1536	5000	3.26
3	0	0	2	1	21	1128	3400	3.01

- Number of candidate parts = 1248
- Tool slots/machine = 60
- One shift operation

Figure 10. Sample Solutions for Rock Island FMS

4.0 FMS ACQUISITION CASE STUDY: GENERAL ELECTRIC

4.1 HOW UNDERSTANDING THE CONFIGURATION SPECIFICATION PROCESS WILL BENEFIT THE BUYER

Although the buyer is not likely to undertake the full task of specifying an FMS, a better understanding of the specification process can be beneficial. Knowing the steps involved, and perhaps being able to carry out some of them himself, will payoff in all phases of acquiring and operating an FMS. From making the initial system specifications to operation on a day-to-day basis, the user is better equipped when he can assess the capabilities and limitations of his system.

This appendix will illustrate the specification process for an FMS with an actual case study. Those areas that are characteristic of FMS's and would be of particular interest to the buyer or user will be emphasized.

The FMS planning exercises provide a point of departure for the development of candidate system configurations, inasmuch as they identify a limited set of parts suitable for FMS production in general, along with a limited set of FMS machines suitable to the parts. Candidate configurations are defined by deriving from these sets particular choices of parts and machines.

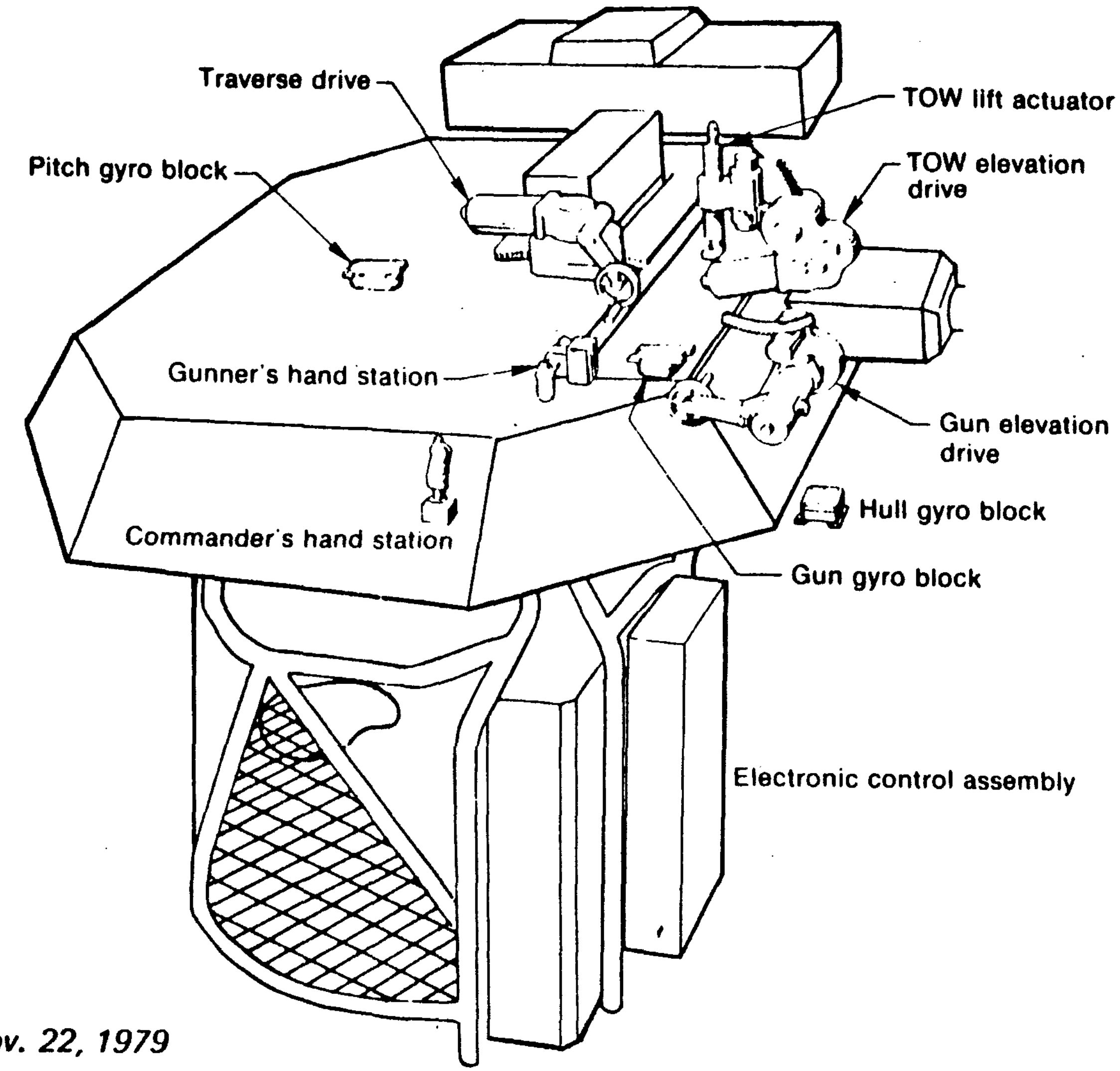
In most cases, the selection process suggests more than one solution. For instance, the problem might be solved for certain values of some constraint, such as the total number of machines allowed. Or more generally, it might be solved under more than one set of guiding rules. The point is that generally several candidate configurations can be identified as choices from the input part and machine sets. They will in general need to be detailed further and compared as to expected performance.

4.2 GENERAL ELECTRIC TURRET STABILIZATION PARTS MANUFACTURING SYSTEM

General Electric Ordnance Systems Division (GEOS), Pittsfield, Massachusetts, has the responsibility to design and manufacture the turret stabilization systems for the Bradley Fighting Vehicle (BFV) and Cavalry Fighting Vehicle (CFV) programs. Figure 11 on page 136 illustrates the major turret stabilization subsystems.

These subsystems require the fabrication of eleven cast aluminum housings and covers. A set of parts for one vehicle is called a "ship set". Figure 12 on page 137 lists the individual parts for a ship set and gives the approximate sizes. All of the parts have fairly thin sections, and are light and small enough to be manually handled. The parts also had severe accuracy requirements.

Early in the program, a decision was made to have the parts manufactured, at least initially, by outside job shops. At the same time, GEOS contin-



Machine Design Nov. 22, 1979

Figure 11. IFV/CFV Turret Stabilization

Part Sequence Number	Part Name and ID Number	Number of Drawings	Part Size (in.) High x Wide x Thick
	Traverse Drive		
1	12292-354 Top	(2)	8-1/2 x 10 x 10-1/2
2	12292-327 Middle	(2)	12-1/2 x 8 x 2-3/4
3	12292-330 Lower	(2)	16-1/4 x 6-1/4 x 6-1/4
	Tow Elevation Drive		
4	12292-353 Housing	(2)	11 x 15 x 7-1/4
5	12292-359 Cover	(1)	12 x 10 x 2-1/4
	Gun Elevation Drive		
6	12292-358 Housing	(3)	14 x 11 x 9-1/2
7	12292-395 Cover	(1)	8-1/2 x 10-1/2 x 1-1/4
	Tow Lift Mechanism		
8	12292-396 Housing	(3)	10-1/4 x 13 x 5-1/4
	Manual Drive		
9	12292-294 Top Cover	(1)	10-1/2 x 13-1/4 x 3/8
10	12292-393 Housing	(2)	10-1/2 x 19-1/2 x 5
11	12292-397	(1)	3-1/2 x 9-1/8 x 3/8

Figure 12. Turret Stabilization Part Set

ued to consider eventual manufacture of the parts in-house. At this point, Draper Laboratory became involved, assisting General Electric in the analysis of alternative in-house systems. Emphasis was placed upon FMS alternatives with configurations, ranging from largely manual through fully automated systems also considered.

The primary issues that guided this study included:

1. Machining accuracy (specifications, environment, inspection).

2. Manufacturing reliability (redundancy and repairability).

3. System manufacturer responsibility (guarantees and subsystem compatibility).

4. Cost per part.

5. Investment strategy and accounting policy.

The most important issue is accuracy. There are tradeoffs between stringent specification tolerances, the accuracy and associated cost of production, and the manner of inspection and acceptance. It was not possible for any of these factors to be removed completely. Tolerances could not be sufficiently relaxed nor could the parts be redesigned for manufacture to the point that a general-purpose machining center could produce them. The highest precision machining centers or an array of manual boring mills capable of meeting the original high tolerance levels were limited due to cost.

The method of inspecting the precision parts was also considered very important and complicated the decisions. Temperature control was a factor. Inspection was allowed in the fixture in order to ease the difficulty of achieving the tight tolerances in the free state, but temperature at measurement was, as yet, a free variable.

It appeared that to achieve the targeted accuracy specification it would be necessary to use some or all of:

- Environment temperature conditioning.

- Part/fixture/pallet temperature soaking.

- Machine temperature conditioning.

- Coolant temperature conditioning.

- Inspection machine or gauging assemblage temperature conditioning.

4.2.1 Process Planning

The alternative systems synthesis and analysis tasks first required the development of detailed process plans for the parts. Initially, standard "machinability data" were used to develop the machining times. These feeds and speeds (especially for certain operation types) were dramatically higher than are the customary practice at GEOS for machining precision

After a lengthy sequence of iterative modifications of the assumed machining practices and fixturing, a set of machinability data has evolved which was the basis for the alternative system configuration and performance estimates. It was decided that "window-frame" fixtures would be used, and clamping ears were added to all parts. Consequently, the initial number of setups (and associated fixtures) was eventually reduced by nearly 50% for the eleven parts.

The calculated total machine operation time required to machine a nominal production rate of 50 ship sets per month is close to 300 hours, approximately the number of hours available in a two-shift month. Since dedicated spindle capacity comes in quantum units and since time allowances for setup, maintenance, and material handling inefficiencies were included in the estimate of production time, at least a two-spindle FMS was found to be necessary. Manually operated precision machines and bolted (nonpalleted) fixtures could also require as many as eight or more machines to produce the 50 ship sets per month within the available two shifts.

The count of serially sequenced tools (not all unique) required to machine a complete ship set is 345. Some tools (especially end mills) are assumed to perform a number of unit operations in a sequence without requiring a tool change. Also, drill, tap, spotface, or chamfer operations may often come in sets so that a single tool (drill, for instance) chucking can be used to machine a set of holes. Each set is dealt with as a unit operation. There are only a few combined unit operations in this tool count. That is, some tools drill and chamfer at the same time. A few other tool assemblies may perform two or more unit operations in sequence as the tool proceeds into the cuts. It is possible to further reduce the number of sequential tools by combining more unit operations onto a single tool assembly.

The number of <u>unique</u> tools in the selected sequence is 190. It may or may not be cost effective to "merge" the tool set and eliminate duplicated tools. Factors, such as the required tool distribution over the several machines, limited on-machine tool storage capacity requiring batch production cycles, tool life limitations, tool storage search time, cutting time of operations simultaneous with tool search, etc., may make duplication of certain tools cost effective. Each set of identical tools and their tool-in-chain and operations-on-machine distributions have to be considered on their individual merits. Also, all production/inventory policies, batch reconfigurations, and tooling placement are strongly inter-related in their effect upon an optimal tooling configuration.

4.2.2 Computer-Aided System Design Tools

Many combinations of inter-related machine parameters, machinability assumptions, fixture/setup configurations, tooling configurations, etc., led to a large number of successive and alternative process plans. To facilitate examination of changes in each of these combinations, a cycle time calculation program (CTIME) was developed to aid in the calculations and documentation. (See Volume V for a User's Manual.) The repetitive configuration design computations were coded for high throughput so that changing any number of input parameters would quickly produce an updated output.

Figure 13 on page 141 schematically shows some of the computerized system design tools that were developed for this systems design and analysis problem. Figure 14 on page 142 is a typical page of CTIME input/output printout (for part 359, the Tow Elevation Drive Cover) which documents the process elements and sequence assumptions along with the resulting operation times.

Figure 15 on page 143 illustrates typical machinability assumptions (feeds and speeds for the assumed operation types) that are the second primary input to the CTIME program. Figure 16 on page 144 is a typical assumed machine-parameters set which is the third primary input to CTIME. The right side of the computer printout page, shown in Figure 14 on page 142, documents the resulting process plans, time elements, setup orientation and machine visitation sequences.

The process plans and sequences are used to formulate part batches and machine balancing strategies within the specified machine and tool storage capacities in such a way as to satisfy production and inventory cycle goals. This process has to be repeated every time there is any significant variation in the input parameters. Therefore, an automatic Batching/Balancing Program (BATCHBAL) was developed which could quickly generate the data input required for a simulation. The Simulation Program (developed for this application) computes the performance parameters for each system alternative. This performance data is used as input to several economic analysis programs developed to permit comparative evaluations of per part cost, alternative investment strategies, and accounting policies.

The evolution of system concepts is a very iterative process. Without an integrated system of fast and easy to use tools, it would be practically impossible to evolve a realistic best-set of alternatives. There are too many variables and branching points to obtain manually a good set of alternative systems within a reasonable amount of effort and time.

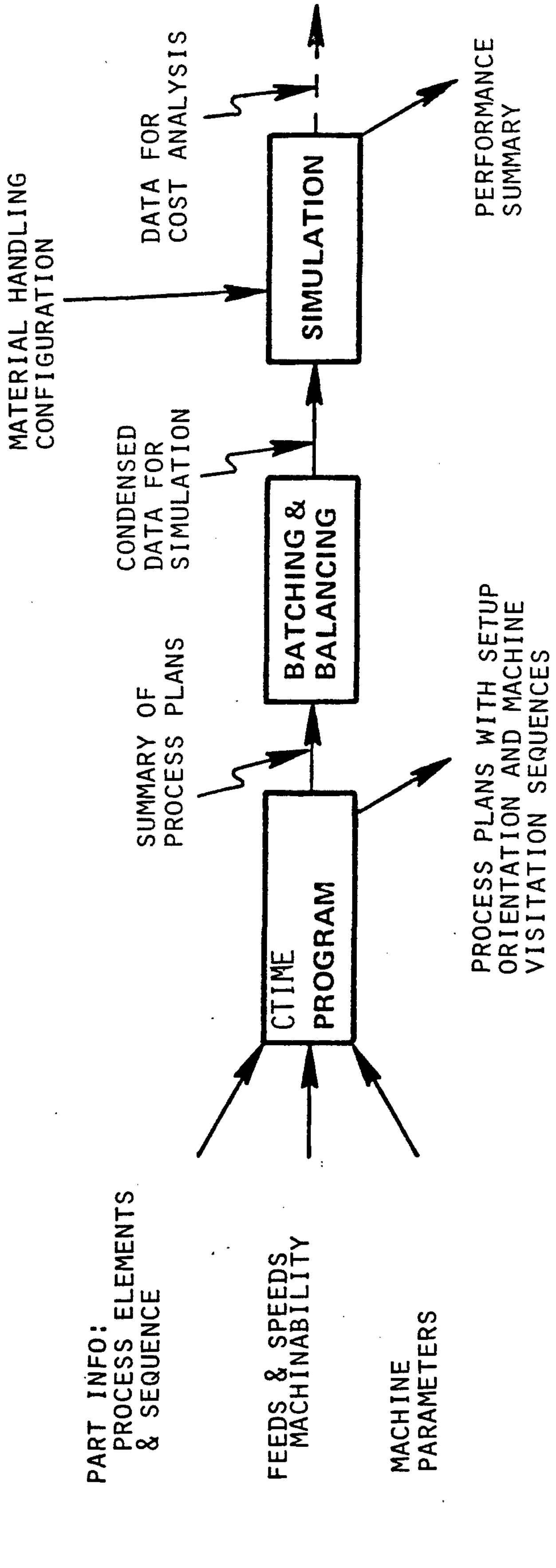


Figure 13. System Design Tools

PART 12292359 PROCESS PLANNING CHART PAGE 1

TOW ELEVATION DRIVE / COVER

OPERATION NO	N	NAME	TOOL TYPE	T	DIA	COMMENTS	LENGTH OF CUT	MACH TYPE	DEAD DIST	TOOL LIFE	OP NO	CUTTING SPEED AND FEED SFM	RPM	FPR	IPM	MACH TIME	DEAD TIME	TOTL TIME
01		PLU1&6	R/MILL	6	1.500		38.				01	600.	1528.	0.024	36.7	1.04	0.20	1.24
02		PLU1	R/MILL	6	1.500		32.				02	600.	1528.	0.024	36.7	0.87	0.03	0.91
03		PLU2	R/MILL	6	1.500		10.				03	600.	1528.	0.024	36.7	0.27	0.03	0.31
04		PLU3&3N	R/MILL	6	1.500		5.				04	600.	1528.	0.024	36.7	0.14	0.03	0.17
05	3	S11	C/MILL	6	1.500		4.2				05	250.	637.	0.018	11.5	1.10	0.10	1.20
06	3	S22	C/MILL	6	1.500		1.7				06	250.	637.	0.018	11.5	0.45	0.10	0.55
07	3	S32	C/MILL	6	1.500		1.0				07	250.	637.	0.018	11.5	0.26	0.10	0.36
08	3	S42	C/MILL	6	1.500		1.2				08	250.	637.	0.018	11.5	0.31	0.10	0.41
09	8	HB1-8	DRILL		.281		0.5				09	150.	2039.	0.003	6.1	0.65	0.43	1.09
10		PLU3&3N	F/MILL	6	1.500		5.0				10	600.	1528.	0.012	18.3	0.27	0.20	0.47
11		PLU2	F/MILL	6	1.500		10.				11	600.	1528.	0.012	18.3	0.55	0.03	0.58
12		PLU1	F/MILL	6	1.500		32.				12	600.	1528.	0.012	18.3	1.75	0.03	1.78
13		PLU1&6	F/MILL	6	1.500		38.				13	600.	1528.	0.012	18.3	2.07	0.03	2.11
14		S11	S/BORE		2.824		1.56	P			14	500.	676.	0.005	3.4	0.46	0.20	0.66
15		S22	S/BORE		2.037		1.56	P			15	500.	938.	0.005	4.7	0.33	0.20	0.53
16		S32	S/BORE		1.840		1.56	P			16	500.	1038.	0.005	5.2	0.30	0.20	0.50
17		S42	S/BORE		1.849		2.25	P			17	500.	1033.	0.005	5.2	0.44	0.20	0.64
18		S11	F/BORE		2.8345	(+6-0)	1.56	P			18	500.	674.	0.002	1.3	1.16	0.20	1.36
19		S22	F/BORE		2.0471	(+6-0)	1.10	P			19	500.	933.	0.002	1.9	0.59	0.20	0.79
20		S32	F/BORE		1.8503	(+6-0)	1.10	P			20	500.	1032.	0.002	2.1	0.53	0.20	0.73
21		S42	F/BORE		1.8690	(+5-0)	.75	P			21	500.	1022.	0.002	2.0	0.37	0.20	0.57
22		S12	WR KEY		1.500		5.0	P			22	600.	1528.	0.016	24.4	0.20	0.20	0.40
23	2	S23-24	WR KEY		1.500		2.1	P			23	600.	1528.	0.016	24.4	0.17	0.07	0.24
24	2	S33-34	WR KEY		1.500		1.5	P			24	600.	1528.	0.016	24.4	0.12	0.07	0.19
25	2	HA1-2	DRILL		.221		0.5	P			25	150.	2593.	0.002	5.2	0.19	0.23	0.43
26	2	HA1-2	S/BORE		.230		0.33	P			26	500.	4500.	0.005	22.5	0.03	0.23	0.26
27	2	HA1-2	F/BORE		.250	(+0-7)	0.33	P			27	500.	4500.	0.002	9.0	0.07	0.23	0.31
27R		ROTATE			180.													
28		PLU4	R/MILL	6	1.500		11.				28	600.	1528.	0.024	36.7	0.30	0.20	0.50
29		PLU4	F/MILL	6	1.500		11.				29	600.	1528.	0.012	18.3	0.60	0.03	0.63
30	8	HB1-8	DRILL		.750	(SP/FC)	0.035				30	150.	764.	0.005	3.8	0.07	0.43	0.51

Figure 14. Typical CTIME Program Output

	Surface Feet per Minute	Feed per Tooth (0.001")	Feed per Revolution (0.001")	Feed Inches/ Minute
Rough Mill	600	4		
Finish Mill	600	2		
Contour Mill	250	3		
Drill	150	1		
Tap				30
Form Tool	600	4		
Woodruff Key	600		16	
Semifinish Bore	500	5		
Finish Bore	500	2		

Figure 15. Typical Machinability Input Dataset

	Tool Storage Capacity	Maximum RPM	Tool Change Time (seconds)	Positioning Time (seconds)	Rotary Table Rate °/sec	Pallet Exchange Time (Sec)	Machine Mfgr. and Models
General-Purpose NC	96	3000	5	2	30	40	Ex-Cell-O
Precision Manual	48	3000	60	30	30	60	DeVlieg

Figure 16. Typical Assumed Machine Parameters Dataset Input

4.2.3 System Configuration Alternatives

Along with the various process plans and analysis tools, a set of configuration alternatives was developed representing a spectrum of systems from traditional, primarily manual, job shop practices to fully automated FMS configurations. Figure 17 on page 146 is a matrix illustrating some principle parameter categories used in differentiating the systems that included:

- Manual versus automated material handling.
- Representative material handling techniques.
- Bolted versus palleted fixtures.
- Representative machine assemblages.

Four representative system combinations (indicated as Configurations 1 through 4 in Figure 17 on page 146) are shown schematically in Figure 18 on page 147 through Figure 21 on page 150, respectively.

Early in the process of estimating machining times, it was determined that palleted fixtures loaded at a central specialized station (rather than loaded individually at each machine station onto a bolted down fixture) could dramatically reduce unproductive (noncutting) machine time and thereby reduce the number of machines required. Therefore, all of the primary alternatives assume centrally loaded palletized fixtures.

Configuration 1 (Figure 18 on page 147)

Configuration 1 is based on a combination of several manual precision boring mills and a general-purpose NC machining center. Estimates indicate (even assuming palletized fixtures) that four precision manual machines would be required (for the nominal 50 ship sets per month, two-shift production). A potential advantage of these manually operated precision machines is that through use of manual in-process gauging and compensation, the resulting machining accuracy would be better than all but the most precise automated machines.

Only one general-purpose machining center would be required to handle the standard accuracy machining production load. Another general-purpose machining center is shown in phantom because of concern about possible catastrophic system downtime if reliance is placed solely upon a single machine. The extra capacity afforded by a redundant machine is not needed for this level of production, but may be necessary to avoid a dangerously weak link in the BFV production schedule. Production of additional part types could be used to make redundancy more economic.

Configuration 2 (Figure 19 on page 148)

Configuration 2 assumes a mixture of precision and general-purpose automated machining centers. Only one of each is required to satisfy the nominal production rate. Here again, the requirement for high production might dictate a redundant machine of each type.

		Bolted Fixtures	Palleted Fixtures		
MANUAL	Machine / Material Handling	O GP Mach Center (1) Precision Boring Mills (6)	A GP Mach Center (1) Precision Boring Mills (4)	B GP Mach Center (1) Precision Mach Center (1)	C Precision Mach Center (2)
MANUAL	I Manual	Job shop			
AUTOMATED	II Carousel Loader	(N/A)			
	III Line (conveyor or cart)	(N/A)			
	IV Loop (conveyor or cart)	(N/A)			

Figure 17. General Configuration Alternatives

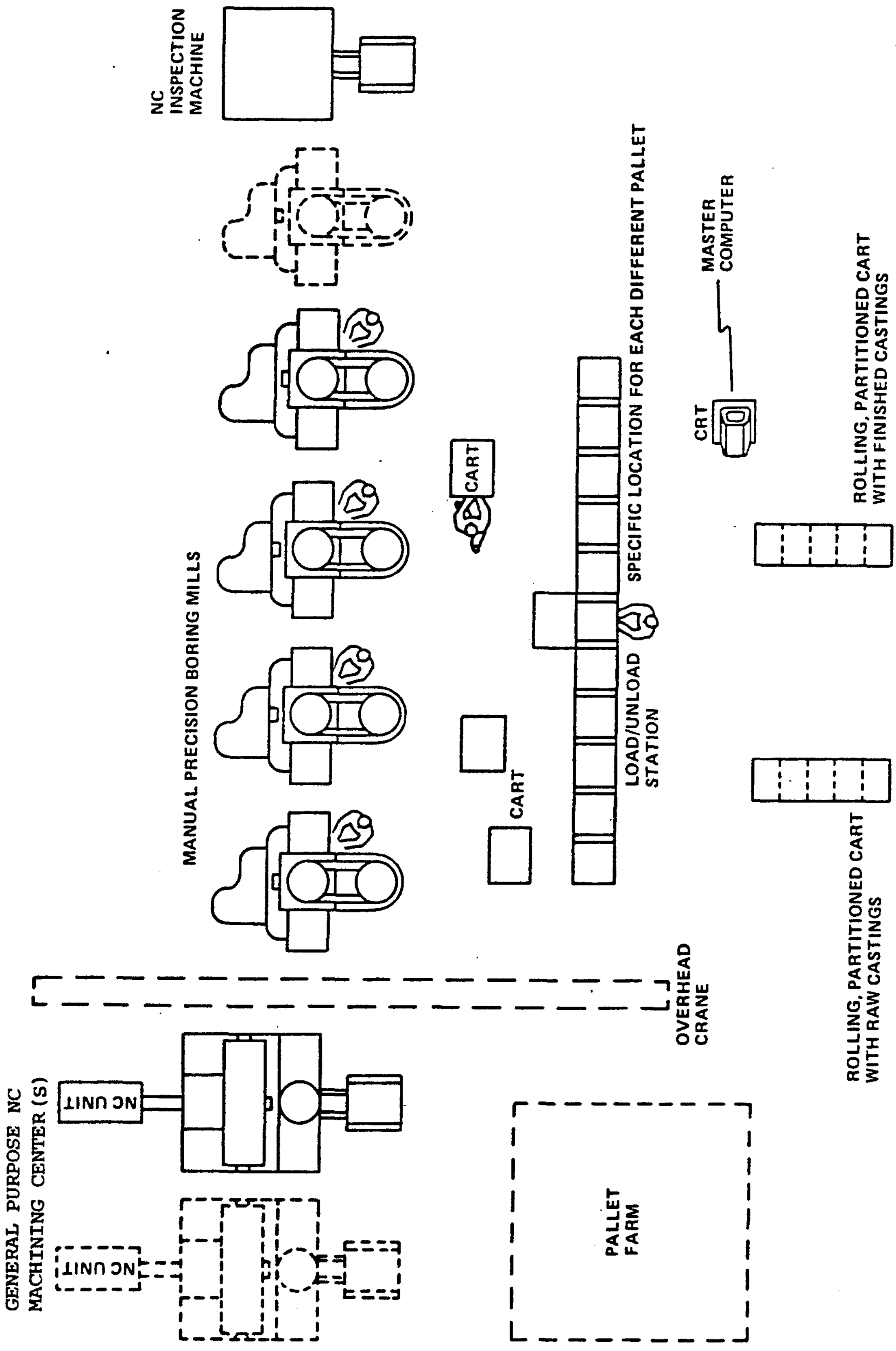


Figure 18. System Configuration 1

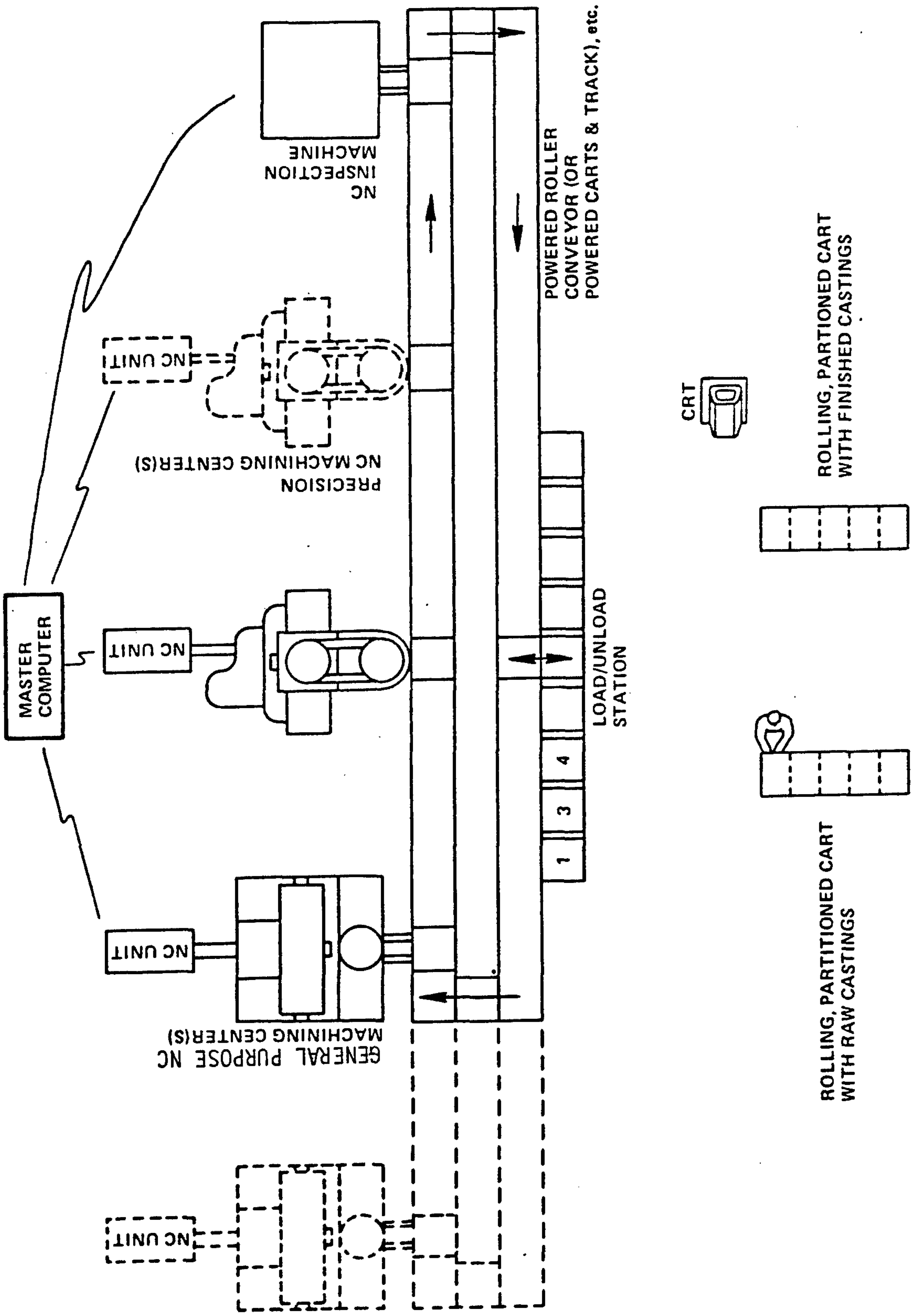


Figure 19. System Configuration 2

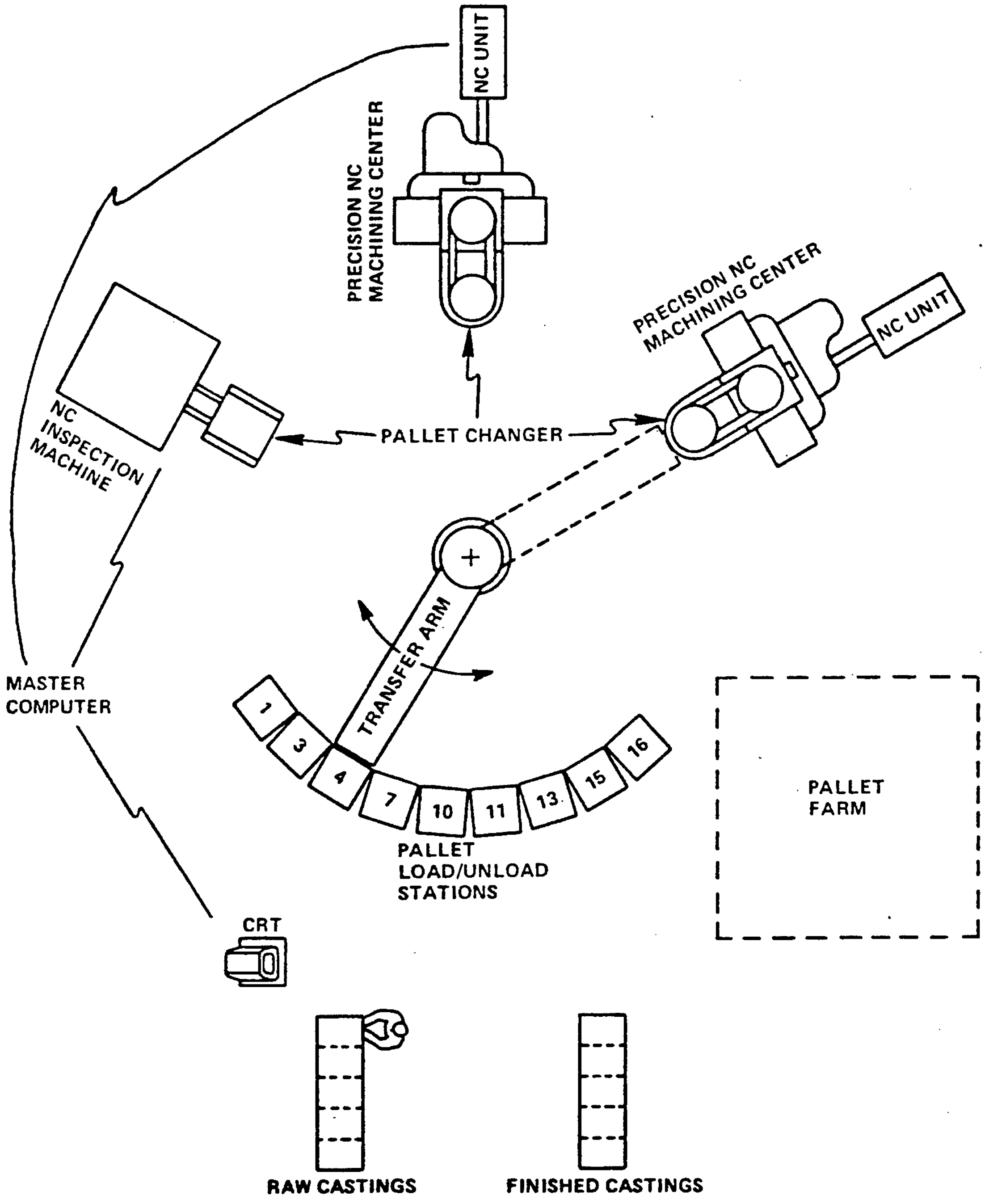


Figure 20. System Configuration 3

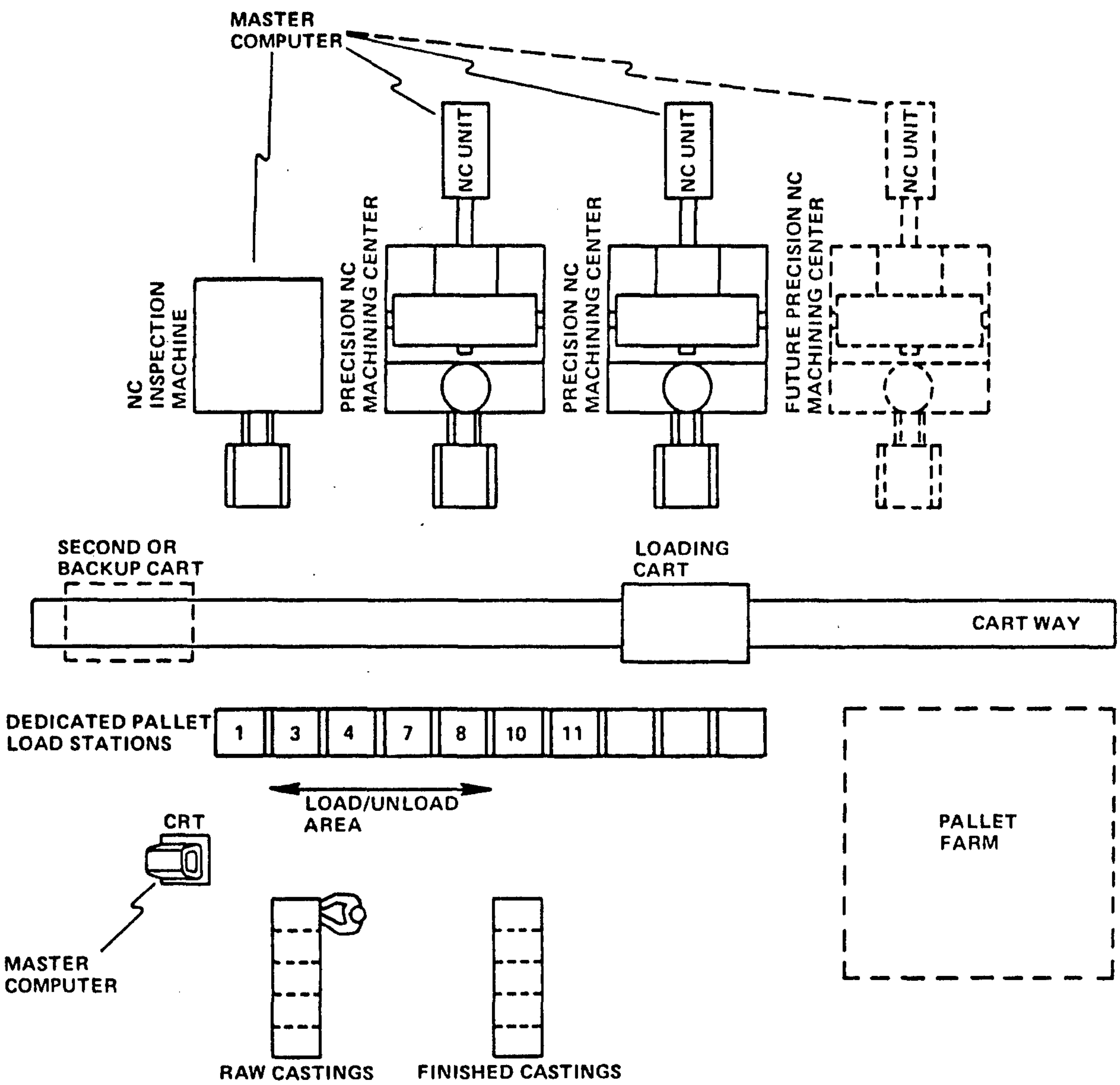


Figure 21. System Configuration 4

This configuration incorporates an automated one-way loop pallet transport system. One-way links (loops or more complex networks) are most common in large FMS systems composed of many work stations. It turns out that the pallet transport frequency and duration is not high enough in this system (few machines and relatively long station residence) to warrant the increased complexity. If redundant machining centers and an automatic inspection machine were incorporated for a total of five stations, then a one-way loop might be more attractive. This enlarged system would probably only make economic sense though for considerably higher than nominal production volumes.

Another potentially troublesome issue for Configuration 2 is that of machine and machine-manufacturer compatibility. There are relatively few manufacturers who have in their product line both general-purpose and high-precision machining centers which are amenable to integration into an FMS system. The interfacing and integration of different manufacturer's hardware, software, responsibility, and organization is generally a costly and time-consuming task. Who is going to take the responsibility? The user? One of the suppliers? A fourth party? In any event, it would generally cost significantly more to combine system elements provided by different manufacturers.

Configuration 3 (Figure 20 on page 149)

Configuration 3 is based upon the use of two essentially identical precision machining centers. Even though the extra precision is not utilized on a routine basis and will cost more, in this particular application this approach appears to be very cost effective because of the intrinsic redundancy and the avoidance of compatibility problems. Also, it results in reducing the frequency of the material handling movements by nearly half, since the "roughing" and precision work can be done on the same machine thereby allowing the use of less expensive material handling.

The material handling system assumed in Configuration 3 is a transfer arm (possibly bidirectional) which could readily serve these machines in a minimum of space. There is no full redundancy in this material handling technique (as is the case for Configuration 2 as well), but it is quite simple and should be reliable and quick to repair. The backup for any signficant downtime would be manual carts, similar to those assumed for Configuration 1. The transfer arm could be pushed out of the way to allow access by the carts. (Note that this type of manual accessibility would generally not be possible for Configuration 2.) One drawback of this material handling scheme is that it could have only very limited expansion potential without radical reconfigurtion of the layout.

Configuration 4 (Figure 21 on page 150)

Configuration 4 is also based upon the use of duplicate precision machining centers. The difference from Configuration 3 is the incorporation of a linear cart-way which accesses a set of pallet load stations on one side and the machines on the other. The cart-way can be largely a passive guideway with very little that can fail in a catastrophic way. Two (or more) "active" automatic carts can move along the guideway, thereby providing redundancy in case one should fail. In general, only one cart is required to easily service the scheduled pallet movements. The other cart could be parked at one end (and serviced) while the other one is active.

4.2.4 On-Line Inspection

In all of the four configurations illustrated, there is an automatic inspection machine shown somewhere on the line. Inspection-in-the-fixture is either an allowance or a requirement, as the case may be, listed on the blueprint specifications. Therefore, an inspection station would be appropriate on the line. The question is one of manual versus automated inspection techniques.

Some of the machining tolerances are so tight that they could require the most precise automatic inspection machines available. Specialized cluster fixtures and plug gauges might serve just as well. Yet a full setup of specialized gauges would probably cost as much as a very precise automatic inspection machine, and could require considerably more manpower support.

On the other hand, manual gauging would not cause the same potential compatibility problem as there could be between an automated inspection machine and the rest of the system. There are almost no manufacturers who might make both precision machining centers and precision automatic inspection machines. Also, some of the specialized manual inspection fixtures and gauges will probably already exist by the time an automated system might be built.

Still, automatic inspection may be more attractive due to its versatility, programmability and supplemental features. Engineering changes, automatic monitoring of process trends, sampling algorithms, automatic record and reporting systems, special and unanticipated problems requiring ad hoc inspection procedures, modification of acceptable tolerance limits, etc., could be programmable, in contrast to methods using specialized gauges.

4.2.5 System Performance Estimates

There are a number of performance parameters which are of particular interest in comparing alternative system configurations, design parameters, and operating policies.

4.2.5.1 Production Rate

The upper limit on the production rate is determined by the total time required to cut the metal, as specified by the process plans. Machine specific "unproductive" time required for tool search, tool change, fast feed, spindle speed limitations, force or power limitations, pallet reorientation, pallet/setup change, etc., and material handling "inefficiencies" which may cause a machine to wait will increase the required production time. Another portion of the total production time (which is the most unpredictable, and potentially the most significant and most troublesome) includes all "system-off" time. System-off time includes: system start-up and shutdown procedures, shift change, precision tool compensation adjustments, batch changeover, maintenance, unscheduled downtime, engineering change implementation, mission evolution interruption (more or fewer or different parts added to the set), etc.

The first three production factors (process time, noncutting machine operations, and material handling delays) are relatively predictable, whereas only "reasonable" (industry experience) estimates can be made for system-off time. Figure 22 on page 154 is a matrix listing estimated production rates for some of the systems considered, based upon generally equivalent parameters for comparison. Machine parameters are somewhat different for each case since different machine models were judged to be most appropriate for the various configurations.

4.2.5.2 Machine Utilization Versus Material Handling

"One hundred percent machine utilization" means that a machine never has to delay its operation waiting for a part. (Obviously, there is still a significant, or possibly controlling, machine fraction of operation time during which metal is not being cut due to the second factor discussed in the preceding section). Balancing and the efficiency of the material handling system (the third factor) will determine the percent machine utilization, that is:

$$\text{MACHINE UTILIZATION} = \frac{\text{MACHINING + "UNPRODUCTIVE" TIME}}{\text{TOTAL SYSTEM "UP" TIME}}$$

In general, estimated machine utilizations were not "much" below 100% (for all cases) since the balancing allocations produced almost exactly equal machine loadings and simple pallet changer "queues" could avoid nearly all machine waiting time.

4.2.5.3 Fixtures/Pallets Required

For all automated machine configurations (columns A, B, and C), only one fixture (along with mated pallet) of each type was required for nominal production rates. No reduction in machine utilization was found to be caused by only allowing one fixture of each type, since there would always be much more pallet types active (used for a specific batch) than machines. It appears that this will be true even if an "in-pallet" inspection station is included in the line. Thus far, GEOS has not pro-

PALLETED FIXTURES

Machines / Material Handling	GROUP A (1) General Precision Machining Center (4) Precision Boring Centers		GROUP B (1) General Precision Machining Center (1) High Precision Machining Centers		GROUP C (2) High Precision Machining Centers		
Configuration:	A1	A2	B1	B2	C1	C2A	C2B
I. Manual	75	66	56	51	60	74	80
III. Two-Way Straight Line (Conveyor or Cart)	80	78	67	64	69	84	88
IV. One-Way Loop (Conveyor or Cart)	79	78	67	63	67	81	88

Figure 22. Matrix of Monthly Production Rates

vided sufficient definition of the inspection functions to make precise estimates.

If the production rate were to be increased dramatically, then the number of machines might approach or surpass the number of active fixture types, in which case, duplicates of some or all of the fixtures would be required. Another reason for duplicate fixtures (and at least a few pallets) is redundancy (whatever the specified level of production). It is always possible for a fixture to be damaged and reduce production. Fewer duplicate pallets would be required since they are essentially identical, but it still may be appropriate to have one pallet "permanently" attached to every fixture in order to avoid a production delay created by the mating and alignment operation in assembling the needed fixture/pallet.

4.2.5.4 Batch Size Versus Tool Complement Storage Capacity

The maximum batch size (the number of part types that can be in active production at one time) is primarily determined for any given system configuration by tool-storage capacity. If all of the tools required for a full ship set of General Electric parts could be resident in the machines at one time, then all the parts could be actively produced all of the time. Any part of the ship set, any replacement or spare, could be programmed through production at any time without a batch change-over procedure. In general though, few standard model machining centers have sufficient capacity for two machines to hold even a fully merged tool set of 190 tools, much less a full serial sequence tool set of 345 tools. Two specially built machines with maximum tool capacity could hold a fully merged tool set with a few spares. But the limited speed of the existing linear access tool chains, etc. would probably increase tool access and replacement time for a fully merged tool set to the point that it could not be executed in less than tool cutting times. The production rate of the system could be reduced to the point that a month's production (full ship set inventory cycle) would actually take longer than for a batch production policy, with its attendant change-over delays.

Tool life is another factor that can affect the batching policy. It is desirable to avoid replacing tools during a batch production run and to integrate the tool replacement function into the batch change-over procedure. Some preliminary life estimates have been made which indicate that the expected life of nearly all of the tools is longer than a usual batch production run. A few of the milling cutters, etc., that get heavier usage might be duplicated, and thereby avoid any such interim scheduled tool replacement time. Tool life could be more precisely determined as actual production evolves, and this data could be fed back into successive batch planning iterations.

The necessary batching policy will also be affected by the configuration of the system and the combination of machines selected. Configurations A versus B versus C all "prefer" different operation/tool distributions amongst their machine assemblages. These different tool distributions can also affect the number of batches required and the selection of part type combinations for the individual batches. Therefore, the number of batches required is specific to configuration and machine, as well as specific to tool storage capacity. Figure 23 on page 157 lists the number of batches (and associated batch sizes) for selected configuration/machine combinations.

4.2.6 Cost Data

The alternative system configuration designs combined with the associated performance data form a basis for making estimates of expected return on investment (ROI) for given production policies. Investment analysis necessitates defining a range of cost parameters, such as:

1. Capital Equipment Costs

    a. Machining center, other station machines.

    b. Material handling systems.

    c. Control and management computer systems, etc.

    d. Fixtures and pallets.

    e. Tools.

    f. Inspection systems.

    g. Coolant and chip management systems.

    h. Environment, part/fixture/pallet, machine, and coolant temperature conditioning.

    i. Foundations, utilities, space construction or allocation.

PALLETED FIXTURES

Machines / Material Handling	GROUP A (1) General Precision Machining Center (4) Precision Boring Centers		GROUP B (1) General Precision Machining Center (1) High Precision Machining Centers		GROUP C (2) High Precision Machining Centers			
Configuration:	A1	A2	B1	B2	C1	C2A	C2B	
I. Manual	2 (5,6)	2 (4,7)	3 (3,3,5)	4 (2,3,2,3)	4 (3,2,3,3)	3 (3,4,4)	2 (4,7)	Batches Parts/Batch
III. Two-Way Line (Conveyor or Cart)	2 (5,6)	2 (4,7)	3 (3,3,5)	4 (2,4,2,3)	4 (3,2,3,3)	3 (3,4,4)	2 (4,7)	
IV. One-Way Loop (Conveyor or Cart)	2 (5,6)	2 (4,7)	3 (3,3,5)	4 (2,4,2,3)	4 (3,2,3,3)	3 (3,4,4,)	2 (4,7)	

Figure 23. Number of Batches (and Batch Sizes)

2. Recurrent Production Costs

a. Shift, shift-splitting, hours, and vacation policy, etc.

b. Defining work rules, job categories, manual tasks, and associated costs per man-hour.

c. Space for production, inventory, storage, tool setup.

d. Utilities.

e. Coolant and other consumables.

f. Castings.

g. Replacement tools.

h. System repair parts, spare parts inventory.

3. Accounting Policy, Investment Strategy, Management Decisions

a. Overhead allocation policy.

b. Applied versus distributed labor allocations.

c. Return on investments or other basis for determining cost of capital.

d. Expected inflation (of the many cost factors, and of the out-of-house manufacturing alternative(s)).

e. Division of required capital and operating costs between GEOS and other GE divisions, Army, etc.

f. Incremental costs and benefits of conversion from outside to in-house production (starting from actual initial condition at some estimated point in time).

g. Direct costs and costs-of-risk of entrance into new (unfamiliar) technology and organization.

h. Direct costs and cost-of-risks of competing alternatives.

Listed below are specific cost categories which have been developed for the investment analysis at General Electric. It must be kept in mind, however, that some of this reflects corporate policy at General Electric and might be different for another company.

1. Machines: The following table illustrates the range of equipment examined. The equipment listed includes a CNC unit, coolant fittings, NC rotary index table, pallet exchanger, special equipment to permit the machine to obtain the required accuracy, and the largest tool changer possible.

General Precision Equipment

Burgmaster HTC330

Kearney and Trecker No. 200

Ex-Cell-O No. 108

High Precision Equipment

DeVlieg Manual

DeVlieg JMC 4340

Sundstrand OM 2A

Sundstrand OM 80

Giddings and Lewis MC 4000

Wotan Rapid 0

2. Computer for hierarchical control of required machinery and Material Handling System.

3. Chip control and Coolant Maintenance: In-floor, chip and coolant trough/conveyor, pallet/fixture wash station straddling material handling system at some point, coolant conditioner (cooler, etc.), cyclotron, and guarding for environmental control of part on the machine.

4. Fixtures, window frame.

5. Pallets, probably meehanite.

6. Tooling, three complete sets.

7. Casting Cost, present quote (50 ship sets/month).

8. Labor cost, present quote (50 ship sets/month).

9. Inspection machine, three-axis NC with pallet-exchanger, (might be considered special equipment).

10. Machine Rate.

11. At General Electric, crib activities, NC programming and verification, scrap/rework are charged directly to the project, but there must be some allocation basis used to spread the cost over all of the parts (like overhead).

12. Material Handling Equipment:

    Robot.

    In-line track/cart system.

    Conveyor.

    Load/unload station.

13. Installation.

14. Engineering.

15. People Data: At present, one person is required at load/unload station and one master machinist/techician/supervisor is required, both full time. Possible additions include one or two persons full time if the "mover" material handling option is chosen, one or more inspectors and perhaps an upper-level manager. Setup people, maintenance crews, and other indirect labor are accrued cost, distributed like overhead.

16. Time Data: Times are generated by the process planning and simulation programs and vary due to the machine/material handling configuration chosen. Results of the latest simulations for each configuration are given below in minutes per ship set.

Machine Configuration	No.	Mover	Cart	Conveyor
1 NC,4 Manual Precision	A1	192	178	181
1 NC,4 Manual Precision	A2	215	183	184
1 NC,1 Precision NC	B1	257	214	214
1 NC,1 Precision NC	B2	280	222	226
2 Precision NC	C1	240	208	212
2 Precision NC	C2A	194	170	176
2 Precision NC	C2B	180	162	162

4.2.7 Investment Analysis

A computerized investment analysis tool, IAP, was developed to calculate the ROI and payback period for as many as 20 alternative FMS configurations. Figure 24 on page 162 schematically illustrates the input/output structure of the program. Figure 25 on page 163 lists the investment and operating cost per ship set for each configuration.

Exercising the economic models with the data available, it was evident that of the alternative investments, those configurations consisting of two duplicate, high-precision NC machining centers were most desirable. There are inherent advantages associated with these configurations: only one manufacturer is responsible for the machines, interface problems (both material handling system and computer) are lessened significantly, tooling is interchangeable between the two machines and either machine can be used to produce the same parts if the other goes down. Furthermore, parts do not have to be shuttled from machine to machine -- the precision machines chosen have sufficient strength to perform both roughing and finishing operations -- increasing accuracy and decreasing total ship set make span.

Machine configurations of this type were compared using the models. The most desirable investment of those reviewed, given the data available, is a combination of two duplicate high-precision machining centers and a straight-line, computer-controlled material handling system. Included in this configuration is an NC inspection machine.

It has been assumed that two workers will be required full time to operate the system. Three complete shifts per month, using both workers, will be consumed in changing the configuration (tools, fixtures/pallets, castings, programs) over to accommodate batching of production throughout the month. Assuming a general escalation in both vendor and in-house costs of 10% yearly, an inflation rate of 12% and straightline depreciation, the after-tax incremental-return-on-investment (IROI) is 30.5% (32.3% if examined nonincrementally) and the payback period is 3.27 years. Both IROI and the payback period are improved if the vendor cost is assumed to escalate more rapidly than the in-house cost (which is realistic), inflation lessens, and Sum-of-Years-Digits depreciation is used in place of straight-line depreciation. This study is based on a projected production level of 50 ship sets per month. If the requirements increase to 60 ship sets per month, the IROI and payback period again improve.

In addition, an incremental cost analysis was performed for a number of systems in the C column (duplicated precision machines). The base reference consists of two stand-alone DNC precision machining centers plus a fixture loading station and manual material handling, etc., to which increments of automation and other capital equipment subsystems were conceptually added, one at a time including:

- Various automated material handling systems.
- Automated chip handling systems.
- Automatic inspection station.

In general, almost all of the automation alternatives considered would be cost effective within the assumed GEOS cost and policy framework. Figure 26 on page 164 presents the results of this incremental investment analysis.

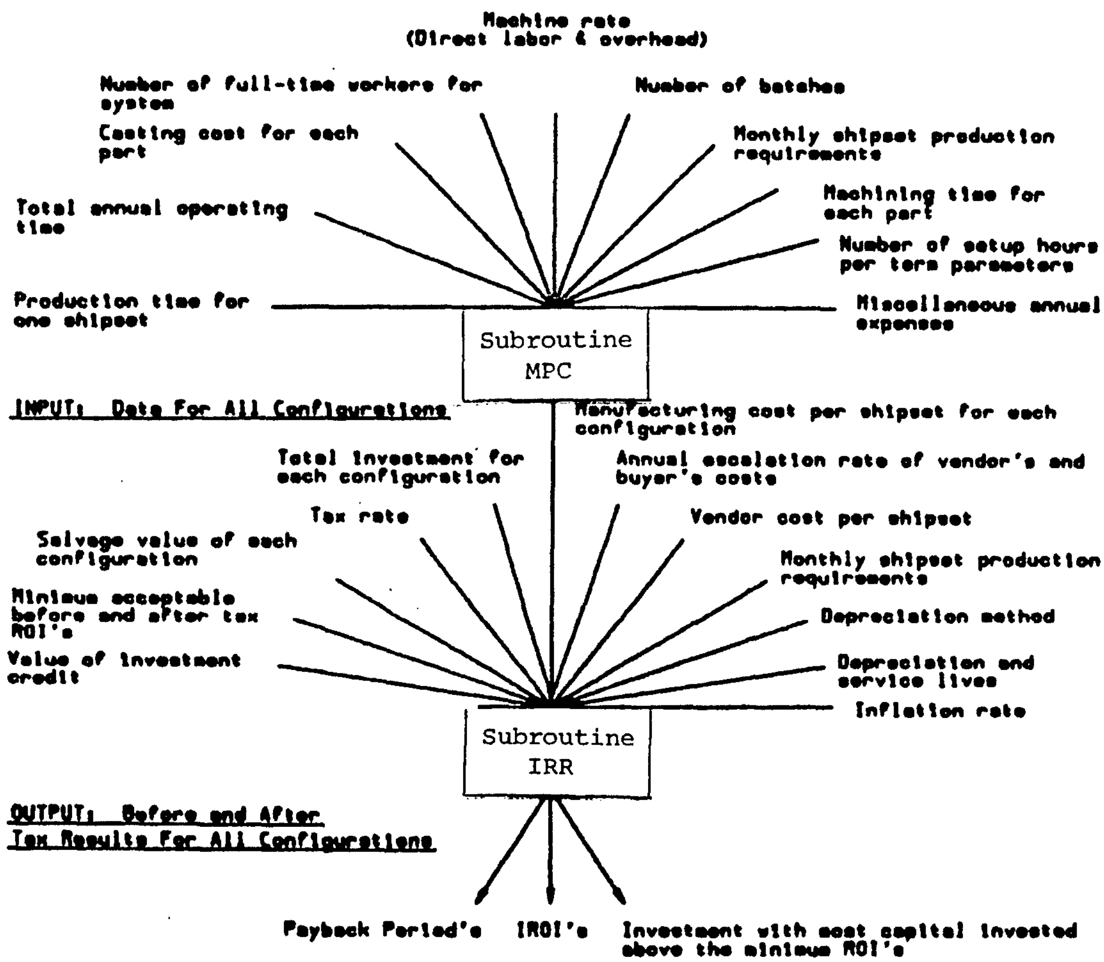


Figure 24. Cost Program Schematic Flowchart Illustrating Input and Output Structure

Configuration/ Material Handling System	A1	A2	B1	B2	C1	C2A	C2B	
	$4,665,050	4,769,755	3,795,001	4,049,755	4,245,000	3,764,600	4,329,000	Investment
Push Cart	$1527,47	1634.80	1113.47	11178.67	1098.67	987.47	946.27	Operating Cost/ Ship Set
	$4,990,000/	5,094,755	4,120,000	4,374,755	4,620,000	4,109,600	4,654,000	
Bidirectional Straight Line Cart System	$1332.27	1350.67	865.00	889.07	870.40	806.00	783.47	
	$5,215,000/	5,319,755	4,345,000	4,599,755	4,845,000	4,334,000		
One-Way Conveyor Loop System	$1342.67	1354.67	865.00	804,40	875.74	814.95		

Figure 25. Comparative Investment and Operating Costs/Shipset for Each Configuration

Configuration C2A	Increment of Capital Cost	Mfg. Cost per Shipset	Incremental Return-on-Investment After Taxes
FMS Without Automatic Material Handling System			
1. (2) Machining Centers with DNC Controls	$3,296,000	$1284.54	33.42%
2. (2) DNC Machining Centers plus Automatic Chip/Coolant Recovery System	320,000	1135.70	28.85%
3. (2) DNC Machining Centers plus Automatic Chip/Coolant Recovery System plus Automatic Inspection Machine	50,000	987.47	117.19%
FMS With Automatic Material Handling System			
1. (2) Machining Centers with DNC Controls	145,000	1071.00	0.00%
2. (2) DNC Machining Centers plus Automatic Chip/Coolant Recovery System	280,000	939.47	7.77%
3. (2) DNC Machining Centers plus Automatic Chip/Coolant Recovery System plus Automatic Inspection Machine	25,000	806.94	196.29%

Figure 26. Incremental Automation Investment Analysis

4.2.8 Procurement Specification

The general conclusion of the technical and economic work is that an FMS is both feasible and attractive for manufacture of the BFV/CFV turret stabilization parts. The concluding task in this phase of the project required writing a procurement specification, supported by information from this study, which would aid potential bidders in defining systems and minimize the bid generation expense of process planning.

Draper Laboratory and GEOS generated a preliminary procurement specification, and GEOS initiated contacts with a number of system manufacturers. The document was written so as to specify functional requirements and not limit the creative ideas, configurations, and organizational options open to potential suppliers.

Each FMS manufacturer has a unique perspective and set of component options available to him in configuring candidate systems which are influenced by:

- The range of their own, and associated companies', product lines.
- Interest in, and ability to produce, specialized machines and other subsystems.
- The realities of subsystem integration compatibility, in cases where it would be necessary to integrate equipment supplied by other manufacturers.
- The magnitude of their back order and alternative business.
- Interest in penetrating into or expanding within the FMS field.
- Resources and capital available during the bidding and manufacturing activity time.
- Many other subjective management, policy, and institutional factors.

These factors for the various system manufacturers can be troublesome but can also be positive factors in the sense that they can give rise to additional ideas and innovations, which ultimately result in a better FMS system.

5.0 EXAMPLE MANAGEMENT INFORMATION REPORTS

Presented in this appendix are sample reports typical of those generated by an FMS control computer. There are utilization reports for various types of FMS stations as well as for pallets and carts. There are also part production and individual route reports.

5.1 CNC-CONTROLLED MACHINE STATION UTILIZATION REPORTS

This class of reports is related to those FMS stations which are individually controlled by a CNC.

Two classes of utilization data are provided: historical machining events and historical operation summaries. Utilization summaries allow further data concentrations in categories of all machines and machine similarity groups.

5.2 STATION MACHINING EVENTS

********************** Individual Station ***********************
Production Events

Machining Center MC:1

Period: 30-SEP-1981 06:55:00 THRU 01-OCT-1981 06:55:00
Operating Hours: 17.0

ROUTE NAME	OPER. NO.	SERIAL NO.	PALLET NO.	START TIME	COMP TIME	ACT TIME (MIN)	STD TIME (MIN)
09/30/81							
21595 MTR.HSG			1	06:55	07:33	38.0	39.0
26409 CRANKSHAFT			2	07:33	07:49	16.0	16.0
45036 HAND HOLE	31		3	07:49	08:16	27.0	29.0
45036 HAND HOLE	34		3	08:16	08:26	10.0	10.0
18671 TOP HEAD	20		4	08:26	08:59	33.0	34.0
18671 TOP HEAD	24		4	08:59	09:09	10.0	10.0
32811 MANIFOLD	42		5	09:09	09:45	36.0	37.0
32811 MANIFOLD	45		5	09:45	09:59	14.0	16.0
26505 COMP.BOD	10		6	09:59	11:47	108.0	110.0
26505 COMP.BOD	12		6	10:47	11:17	30.0	29.0
26540 COMP.BOD	10		6	11:17	12:47	90.0	91.0
26540 COMP.BOD	12		6	12:47	01:10	23.0	25.0
23062 MOTOR COV			7	01:10	01:49	48.5	52.0
. . .							
10/01/81							
. . .							
24540 COMP.BOD	12		6	12:47	01:10	23.0	25.0

****

Explanation of Terms

- REPORT PERIOD: May range over any amount of the data base (if available on the disk or on an active magnetic tape). Range is specified by the system manager.

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- START TIME: Time when cycle start is activated for the part located on the machine table.

- COMPLETE TIME: Time when the last part program's end of program for the part on the table is read.

- ACTUAL TIME: Complete Time minus Start Time minus Inoperable Time.

- STANDARD TIME: Time typically required to execute all the part programs for the part on the current machine. This time is embedded in the part programs to be run.

5.2.1 Station Operation Summary

*********************** Individual Station ************************

Production Summary

Machining Center MC:1

Period: 30-SEP-1981 07:00:00 THRU 30-SEP-1981 15:30:00

Operating Hours: 8.5

ROUTE NAME	OPER. NO.	NUMBER COMPLETE	AVERAGE ACTUAL TIME (MIN)	AVERAGE STAND. TIME (MIN)	AVERAGE VARIANCE (MIN)
21595 MTR.HSG		2	38.5	40.0	- 1.5
26505 COMP.BOD	10	2	108.0	110.0	- 3.0
.					
.					
.					
21595 MTR.HSG	10	WIP	30.0	30.0	+ 0.0

AVERAGE CYCLE PERFORMANCE 97.7%

OPERATION SUMMARY	NUMBER COMPLETE	TOTAL ACTUAL TIME (HRS)	TOTAL STAND. TIME (HRS)	TOTAL VARIANCE (HRS)
	12	6.0	6.5	- 0.5
	WIP	0.5	0.5	+ 0.0

ACTUAL MACHINING TIME		6.5 HOURS		
IDLE TIME		0.5		
INOPERABLE TIME		1.5		
MACHINE PROBLEM	0.6			
PART/FIXTURE PROBLEM	0.0			
TOOLING PROBLEM	0.5		STATION ON-LINE	82.4%
OTHER	0.4		ON-LINE UTILIZATION	92.8%

TOTAL TIME		8.5 HOURS		

****

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- AVERAGE ACTUAL TIME: Average actual time used to execute all the part programs for a given Route Name and Operation Number over the stated Report Period.

- AVERAGE STANDARD TIME: Time typically required to execute all the part programs for a given Route Name and Operation Number on the stated machine. This time is embedded in the part programs to be run.

- AVERAGE VARIANCE: Average Actual Time minus Average Standard Time.

- TOTAL ACTUAL TIME: Actual Time used to execute all the part program over the stated Report Period.

- TOTAL STANDARD TIME: Standard Time to execute all the part programs over the stated Report Period.

- TOTAL VARIANCE: Total Standard Time minus Total Actual Time.

- INOPERABLE TIME: Any time when the machine is incapable of machining. Excludes when waiting for a pallet or a part program. Excludes when program stop is read.

- IDLE TIME: Any time the machine is capable of machining but is not, i.e., waiting for a pallet or a part program.

- AVERAGE CYCLE PERFORMANCE: Average Standard Time/Average Actual Time

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

5.2.2 Station Group Operation Summary

```
*************************  Station Group  *************************
                          Production Summary

                           Machining Center

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Available Hours: 42.5
--------------------------------------------------------------------
                          ACTUAL                     IDLE    INOPERABLE
                 MACHINE  TIME      PERFORMANCE      TIME    TIME
MACHINE GROUP    NUMBER   (HRS).        (%)          (HRS)   (HRS)

    MC
                  MC:2     5.5         64.7           1.5     1.5
                  MC:3     8.0         94.1           0.5     0.0
                  MC:4     3.0         35.3           0.0     5.5
                  MC:5     5.5         64.7           1.5     1.5
                  MC:6     8.0         94.1           0.5     0.0
                           ---         ----           ---     ---
TOTAL                     30.0         70.6           4.0     8.5

                                 STATION ON-LINE              80.0%
                                 ON-LINE UTILIZATION          88.2%
--------------------------------------------------------------------
                          ACTUAL                     IDLE    INOPERABLE
                 MACHINE  TIME      PERFORMANCE      TIME    TIME
MACHINE GROUP    NUMBER   (HRS).        (%)          (HRS)   (HRS)

    VTL
                  VT:1     5.0         82.4           1.5     2.0
                           ---         ----           ---     ---
TOTAL                      5.0         82.4           1.5     2.0

                                 STATION ON-LINE              76.5%
                                 ON-LINE UTILIZATION          76.9%

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- GROUP NAME: Thirty-two characters. Appears in alphanumeric order. Includes all related machines in numerical order.

- ACTUAL TIME: Actual Time used to execute all the part programs over the stated Report Period.

- INOPERABLE TIME: Any time when the machine is incapable of machining Excludes when waiting for a pallet or a part program. Excludes when program stop is read.

- IDLE TIME: Any time the machine is capable of machining but is not, i.e., waiting for a pallet or a part program.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

- PERFORMANCE: Actual Time/Total Time.

5.3 NC-CONTROLLED INSPECTION STATION UTILIZATION REPORTS

This class of reports is related to those FMS stations which are NC-controlled coordinate measuring systems.

Two classes of utilization data are provided: historical inspection program events and historical operation summaries. Utilization summaries allow further data concentrations in categories of all NC-controlled inspection station groups if applicable.

5.3.1 Inspection Station Program Events

```
**********************  Individual Station  **********************
                        Production Events

                     Inspection Station DV:3

Period:          30-SEP-1981  15:55:00  THRU  30-SEP-1981  23:55:00
Operating Hours: 8.0
-----------------------------------------------------------------------
                                START  COMP   ACT    STD
ROUTE           SERIAL  PALLET  TIME   TIME   TIME   TIME
NAME            NO.     NO.     (MIN)  (MIN)  (MIN)  (MIN)  STA   MACH

09/30/81

PN_19_HOUSING   30002   1       14:55  15:15  30.0   33.0   FAIL  2
PN_20_HOUSING    2304   2       15:40  15:59  19.5   18.5   PASS  4,5
PN_213_FRAME    30004   3       16:25  16:55  30.0   32.0   RRUN  5
                                17:05  17:10                NOC1
                                18:10  18:36  31.2   32.0   RPRG
                                18:42  18:50   8.0    8.0   PASS
PN_19_HOUSING    4014           19:10  19:40  30.0   33.0   PASS
       .
       .
       .
PN_980_FRAME    30018   4       23:25  23:55                      9

***********************************************************************
```

Explanation of Terms

- REPORT PERIOD: May range in any amount of the data base (if available on the disk or on an active magnetic tape). Range is specified by the system manager.

- START TIME: Time when inspection program has been completely downloaded to the inspection station.

- COMPLETE TIME: Time when the operator at the inspection station has completed the inspection by pressing one of the available complete pushbuttons ("A", "B", "Cn", "E", or "F").

- ACTUAL TIME: Complete Time minus Start Time minus Inoperable Time.

- STANDARD TIME: Time typically required to run the inspection program for the part. This time is embedded in the operate command of the route.

- INOPERABLE TIME: Any time when the inspection station is incapable of inspecting. Excludes when waiting for a pallet or an inspection program.

- IDLE TIME: Any time the inspection station is capable of inspecting but is not, i.e., waiting for a pallet or an inspection program.

5.3.2 Inspection Station Operation Summary

*********************** Individual Station ***********************
Production Summary

Inspection Station: DV:3

Period: 21-SEP-1981 01:00:00 THRU 28-SEP-1981 01:00:00
Operating Hours: 168.0

ROUTE NAME	OPER. NO.	NUMBER INSPECTED	AVERAGE ACTUAL TIME (MIN)	AVERAGE STAND. TIME (MIN)	AVERAGE VARIANCE (MIN)
PN_19_HOUSING		43	32.0	33.0	- 1.0
PN-20_HOUSING		18	18.5	17.5	+ 1.0
.					
.					
.					
PN_213_FRAME		57	33.2	32.2	+ 1.0

AVERAGE CYCLE PERFORMANCE 92.2%

OPERATION SUMMARY	NUMBER INSPECTED	TOTAL ACTUAL TIME (HRS)	TOTAL STAND. TIME (HRS)	TOTAL VARIANCE (HRS)
	205	120.4	111.3	+ 9.1

TOTAL ACTUAL TIME		120.4 HOURS		
IDLE TIME		41.6	AVER. TIME BETWEEN INSP	4.1 MIN
INOPERABLE TIME		5.6		
MACHINE PROBLEM	1.0			
SHUTTLE PROBLEM	0.8			
TOOLING PROBLEM	1.5			
OPERATOR NOT PRESENT	1.5		STATION ON-LINE	96.5%
OTHER	0.8		ON-LINE UTILIZATION	25.7%
IN-PROCESS TIME		0.4		

TOTAL TIME		168.0 HOURS		

****

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- AVERAGE ACTUAL TIME: Average actual time used to execute all the inspection programs for a given Route Name and Operation Number over the stated Report Period.

- AVERAGE STANDARD TIME: Time typically required to execute all the inspection programs for a given Route Name and Operation Number on the inspection station. This time is embedded in the operate command of the route.

- AVERAGE VARIANCE: Average Actual Time minus Average Standard Time.

- TOTAL ACTUAL TIME: Actual Time used to execute all the inspection programs over the stated Report Period.

- TOTAL STANDARD TIME: Standard Time to execute all the inspection programs over the stated Report Period.

- INOPERABLE TIME: Any time when the inspection station is incapable inspecting. Excludes when waiting for a pallet or an inspection program.

- IDLE TIME: Any time the inspection station is capable of inspecting but is not, i.e., waiting for a pallet or an inspection program.

- AVERAGE CYCLE PERFORMANCE: Average Standard Time/Average Actual Time.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

5.3.3 Inspection Group Operation Summary

```
************************** Station Group *************************
                         Production Summary

                         Inspection Station

Period:           21-SEP-1981  01:00:00  THRU  28-SEP-1981  01:00:00
Available Hours:  336.0
---------------------------------------------------------------------
                             ACTUAL                     IDLE     INOPERABLE
                  STATION    TIME     PERFORMANCE       TIME     TIME
                  NUMBER     (HRS).       (%)           (HRS)    (HRS)

                   DV:3      241.6       71.9           83.2     11.2
                             -----       ----           ----     ----
TOTAL                        241.6       71.9           83.2     11.2

                                      STATION ON-LINE              96.7%
                                      ON-LINE UTILIZATION          74.4%

**********************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- GROUP NAME: Thirty-two characters. Appears in alphanumeric order. Includes all inspection stations in numerical order.

- ACTUAL TIME: Actual Time used to execute all the inspection programs over the stated Report Period.

- STANDARD TIME: Standard Time to execute all the inspection programs over the stated Report Period.

- INOPERABLE TIME: Any time when the inspection station is incapable of inspecting. Excludes when waiting for a pallet or an inspection program.

- IDLE TIME: Any time the inspection station is capable of machining but is not, i.e., waiting for a pallet or an inspection program.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

- PERFORMANCE: Actual Time/Total Time.

5.4 NC-CONTROLLED WASHER/DRYER STATION UTILIZATION REPORTS

This class of reports is related to those FMS stations which are NC-controlled washer/dryer stations.

Two classes of utilization data are available: historical washer/dry program events and historical operation summaries. Utilization summaries allow further data concentrations in categories of all NC-controlled washer/dryer station groups if applicable.

5.4.1 Wash Station Program Events

```
*********************** Individual Station ***********************
                        Production Events

                    Washer/Dryer Station DV:1

Period:          30-SEP-1981  15:55:00  THRU  30-SEP-1981  23:55:00
Operating Hours: 8.0
--------------------------------------------------------------------
                                                          ACT    STD
                   OPER.  SERIAL  PALLET  START  COMP     TIME   TIME
ROUTE NAME          NO.    NO.      NO.   TIME   TIME     (MIN)  (MIN)

09/30/81

21595 MTR.HSG                       1     06:55  07:01    6.0    5.0
26409 CRANKSHAFT                    2     07:01  07:05    4.0    5.0
45036 HAND HOLE     31              3     07:05  07:08    3.0    5.0
45036 HAND HOLE     34              3     07:08  07:12    4.0    5.0
18671 TOP HEAD      20              4     07:12  07:16    4.0    5.0
18671 TOP HEAD      24              4     07:16  07:30    4.0    5.0
32811 MANIFOLD      42              5     07:20  07:24    4.0    5.0
32811 MANIFOLD      45              5     07:24  07:27    3.0    5.0
26505 COMP.BOD      10              6     07:27  07:32    5.0    5.0
26505 COMP.BOD      12              6     07:32  07:37    5.0    5.0
26540 COMP.BOD      10              6     07:37  07:42    5.0    5.0
26540 COMP.BOD      12              6     07:42  07:47    5.0    5.0
23062 MOTOR COV                     7     07:47  07:51    4.0    5.0
21595 MTR HSG VTL                   8     07:51  07:55    4.0    5.0
      .
      .
      .
      .
10/01/81
      .
      .
      .
24540 COMP.BOD      12              6   12:47  12:52    5.0    5.0

********************************************************************
```

Explanation of Terms

- REPORT PERIOD: May range in any amount of the data base (if available on the disk or on an active magnetic tape). Range is specified by the system manager.

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same station more than once on the same route.

- START TIME: Time when washer/dryer program number has been downloaded to the washer/dryer station.

- COMPLETE TIME: Time when the operator at the inspection station has completed the inspection by pressing one of the available complete pushbuttons ("A", "B", "Cn", "E", or "F").

- ACTUAL TIME: Complete Time minus Start Time minus Inoperable Time.

- STANDARD TIME: Time typically required to run the washer/dryer program for the part. This time is embedded in the operate command of the route.

5.4.2 Washer Station Operation Summary

```
*********************** Individual Station ***********************
                        Production Summary

                    Washer/Dryer Station DV:1

Period:          21-SEP-1981  01:00:00  THRU  28-SEP-1981  01:00:00
Operating Hours: 168.0
---------------------------------------------------------------------
                                         AVERAGE    AVERAGE
                               NUMBER    ACTUAL     STAND.     AVERAGE
                      OPER.    WASHED/   TIME       TIME       VARIANCE
ROUTE NAME            NO.      DRYED     (MIN)      (MIN)      (MIN)

21595 MTR.HSG                    10        7.0        5.0      + 2.0
26409 CRANKSHAFT                 12        8.5        5.0      + 3.0
      .
      .
      .
26505 COMP.BOD.VTL               19        9.0        5.0      + 4.0

                                    AVERAGE CYCLE PERFORMANCE 70.1%
---------------------------------------------------------------------
                                         TOTAL      TOTAL
                               NUMBER    ACTUAL     STAND.     TOTAL
                               WASHED/   TIME       TIME       VARIANCE
OPERATION SUMMARY              DRYED     (HRS)      (HRS)      (HRS)

                                205      120.4      111.3      + 9.1
---------------------------------------------------------------------
TOTAL ACTUAL TIME               120.4 HOURS
IDLE TIME                        44.6
INOPERABLE TIME                   2.6
  MACHINE PROBLEM         1.0
  SHUTTLE PROBLEM         0.8         STATION ON-LINE            98.2%
  OTHER                   0.8         ON-LINE UTILIZATION        73.0%
IN-PROCESS TIME                   0.4
                                ------
TOTAL TIME                      168.0 HOURS

**********************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- AVERAGE ACTUAL TIME: Average actual time used to execute all the washer/dryer programs for a given Route Name and Operation Number over the stated Report Period.

- AVERAGE STANDARD TIME: Time typically required to execute all the washer/dryer programs for a given Route Name and Operation Number on the washer/dryer station. This time is embedded in the operate command of the route.

- AVERAGE VARIANCE: Average Actual Time minus Average Standard Time.

- TOTAL ACTUAL TIME: Actual Time used to execute all the washer/dryer programs for a given Route Name and Operation Number of the stated Report Period.

- TOTAL STANDARD TIME: Standard Time to execute all the washer/dryer programs over the stated Report Period.

- TOTAL VARIANCE: Total Standard Time minus Total Actual Time.

- INOPERABLE TIME: Any time when the washer/dryer station is incapable washing/drying. Excludes when waiting for a pallet or a washer/dryer program number.

- IDLE TIME: Any time the washer/dryer station is capable of washing/drying but is not, i.e., waiting for a pallet or a washer/dryer program number.

- AVERAGE CYCLE PERFORMANCE: Average Standard Time/Average Actual Time.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

5.4.3 Washer/Dryer Group Operation Summary

```
*************************  Station Group  *************************
                         Production Summary

                        Washer/Dryer Station

Period:          21-SEP-1981  01:00:00  THRU  328SEP-1981  01:00:00
Operating Hours: 336.0
-------------------------------------------------------------------
                          ACTUAL                   IDLE    INOPERABLE
                 STATION  TIME      PERFORMANCE    TIME    TIME
                 NUMBER   (HRS).       (%)         (HRS)   (HRS)

                  DV:1    241.6        71.9         83.2    11.2
                          ----         ----         ----    ---
TOTAL                     241.6        71.9         83.2    11.2

                                   STATION ON-LINE             96.7%
                                   ON-LINE UTILIZATION         74.4%

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- GROUP NAME: Thirty-two characters. Appears in alphanumeric order. Includes all washer/dryer stations in numerical order.

- ACTUAL TIME: Actual Time used to execute all the washer/dryer programs over the stated Report Period.

- INOPERABLE TIME: Any time when the washer/dryer is incapable of washing/drying. Excludes when waiting for a pallet or an inspection program.

- IDLE TIME: Any time the station is capable of washing/drying but is not, i.e., waiting for a pallet or a washer/dryer program number.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

- PERFORMANCE: Actual Time/Total Time.

5.5 MANUAL STATION UTILIZATION REPORTS

This class of reports is related to those FMS stations where persons perform operations commanded by system displays.

Two classes of utilization data are available: historical manual operation events and historical operation summaries. Utilization summaries allow further data concentration in categories of all manual stations and common station groups if applicable.

5.5.1 Manual Station Operation Events

``` 
*********************** Individual Station ***********************
                        Production Events

                       Manual Station LU:1

Period:           30-SEP-1981  06:55:00  THRU  01-OCT-1981  06:55:00
Operating Hours: 17.0
```

ROUTE NAME	OPER. NO.	SERIAL NO.	PALLET NO.	START TIME	COMP TIME	ACT TIME (MIN)	STD TIME (MIN)
09/30/81							
21595 MTR.HSG	10		1	06:55	06:59	4.0	3.0
21595 MTR.HSG	1		1	06:59	07:02	3.0	2.0
26409 CRANKSHAFT	22		2	07:02	07:05	3.0	3.0
26409 CRANKSHAFT	1		2	07:05	07:08	3.0	2.0
45036 HAND HOLE	35		3	07:08	07:12	4.0	3.0
45036 HAND HOLE	1		3	07:12	07:15	3.0	2.0
18671 TOP HEAD	25		4	07:15	07:18	3.0	3.0
18671 TOP HEAD	1		4	07:18	07:20	2.0	2.0
32811 MANIFOLD	46		5	07:20	07:23	3.0	3.0
32811 MANIFOLD	1		5	07:23	07:27	4.0	4.0
26505 COMP.BOD	13		6	07:27	07:30	3.0	3.0
26505 COMP.BOD	1		6	07:30	07:33	3.0	3.0
26540 COMP.BOD	13		6	07:33	07:36	3.0	3.0
26540 COMP.BOD	1		6	07:36	07:41	5.0	4.0
23062 MOTOR COV	33		7	07:41	07:45	4.0	4.0
23062 MOTOR COV	1		7	07:45	07:51	6.0	6.0
. . .							
10/01/81							
. . .							
24540 COMP.BOD	12		6	12:47	12:50	3.0	3.0
24540 COMP.BOD	1		6	12:47	12:54	4.0	4.0

****

Explanation of Terms

- REPORT PERIOD: May range in any amount of the data base (if available on the disk or on an active magnetic tape). Range is specified by the system manager.

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- START TIME: Time when manual procedure is activated for the part located at the load/unload station.

- COMPLETE TIME: Time when manual procedure is completed for the part at the load/unload station.

- ACTUAL TIME: Complete Time minus Start Time minus Inoperable Time.

- STANDARD TIME: Time typically required to perform manual procedure. This time is embedded in the manual procedure file.

5.5.2 Manual Station Operation Summary

```
**********************  Individual Station  ***********************
                        Production Summary

                      Manual Station LU:1

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 8.5
-------------------------------------------------------------------
                                        AVERAGE    AVERAGE
                                        ACTUAL     STAND.     AVERAGE
                    OPER.    NUMBER     TIME       TIME       VARIANCE
ROUTE NAME           NO.     COMPLETE   (MIN)      (MIN)      (MIN)

21595 MTR.HSG        10        15        5.0        3.0       + 2.0
21595 MTR.HSG         1        10        7.0        4.0       + 3.0
26409 CRANKSHAFT     22        10        5.0        3.0       + 2.0
26409 CRANKSHAFT      1         5        4.0        2.0       + 2.0
45036 HAND HOLE      35        10        5.0        3.0       + 2.0
45036 HAND HOLE       1         5        4.0        2.0       + 2.0
      .
      .
      .

                                  AVERAGE CYCLE PERFORMANCE 89.2%
-------------------------------------------------------------------
                                        TOTAL      TOTAL
                                        ACTUAL     STAND.     TOTAL
                             NUMBER     TIME       TIME       VARIANCE
OPERATION SUMMARY            COMPLETE   (HRS)      (HRS)      (HRS)

                               55        4.6        5.0       - 0.4
-------------------------------------------------------------------
ACTUAL MACHINING TIME         4.6 HOURS
IDLE TIME                     3.7      STATION ON-LINE          97.6%
INOPERABLE TIME               0.2      ON-LINE UTILIZATION      55.4%
                              ---
TOTAL TIME                    8.5 HOURS

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- OPERATION NUMBER: Step number of operate command in the route. Displayed only when a part can visit the same machine more than once on the same route.

- AVERAGE ACTUAL TIME: Average actual time used to execute the manual procedure for a given Part Name over the stated Report Period.

- AVERAGE STANDARD TIME: Time typically required to execute a given manual procedure. This time is embedded in the manual procedure file.

- AVERAGE VARIANCE: Average Actual Time minus Average Standard Time.

- TOTAL ACTUAL TIME: Actual Time used to execute all the manual processes over the stated Report Period.

- TOTAL STANDARD TIME: Standard Time to execute all manual procedures over the stated Report Period.

- TOTAL VARIANCE: Total Standard Time minus Total Actual Time.

- INOPERABLE TIME: Any time when the station is incapable of loading or unloading. Excludes when waiting for a pallet, material, or manual procedure.

- IDLE TIME: Any time the manual station is capable of loading or unloading but is not, i.e., waiting for a pallet, material or manual procedure.

- AVERAGE CYCLE PERFORMANCE: Average Standard Time/Average Actual Time.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

5.5.3 Manual Station Group Operation Summary

```
*************************  Station Group  *************************
                        Production Summary

                          Manual Station

Period:          30-SEP-1981 07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 336.0
-------------------------------------------------------------------
                           ACTUAL                 IDLE    INOPERABLE
                 STATION   TIME     PERFORMANCE   TIME    TIME
                 NUMBER    (HRS).       (%)       (HRS)   (HRS)

                  LU:1       5.5       64.7        1.5     1.5
                  LU:2       5.0       58.8        3.5     0.0
                           -----       ----        ---     ---
TOTAL                       10.5       61.8        5.0     1.5

                                  STATION ON-LINE            91.2%
                                  ON-LINE UTILIZATION        67.7%

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- GROUP NAME: Thirty-two characters. Appears in alphanumeric order. Includes all related manual stations in numerical order.

- ACTUAL TIME: Actual Time used to execute a given manual procedure over the stated Report Period.

- INOPERABLE TIME: Any time when the station is incapable of loading or unloading. Excludes when waiting for a pallet, material, or manual procedure.

- IDLE TIME: Any time the manual station is capable of loading or unloading but is not, i.e., waiting for a pallet, material, or manual procedure.

- STATION ON-LINE: (Total Actual Time + Total Idle Time)/Total Time.

- ON-LINE UTILIZATION: Total Actual Time/(Total Actual Time + Total Idle Time).

- PERFORMANCE: Actual Time/Total Time.

5.6 SYSTEM PART PRODUCTION REPORT

This class of report summarizes all production scheduled and completed by the FMS.

```
************************         FMS         ************************
                    Route Production Summary

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 48.5
--------------------------------------------------------------------
                           NUMBER         NUMBER        DIFFERENCE
ROUTE NAME                 SCHEDULED      COMPLETED        (%)

21595 MTR.HSG                 9              9            - 0.0
26409 CRANKSHAFT             15             14            + 6.7
45036 HAND HOLE              11             12            - 0.1
                             --             --            -----
TOTAL                        35             35              0.0

************************         FMS         ************************
                    Part Production Summary

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 8.0
--------------------------------------------------------------------
FINISHED                   NUMBER
MATERIAL NAME              COMPLETED

MOTO_HOUSING                  8
CRANKSHAFT                   14
HAND HOLE                    22
TOP_HEAD                     46
MANIFOLD                      4
COMB.BOD.J                    7
COMB.BOD.S                    6
MOTOR.COV                    10
                            ---
TOTAL                       117

********************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

5.7 INDIVIDUAL ROUTE EVENT AUDIT REPORT

This report is a chronological list of all stations which have operated on the part. It is especially useful for backtracking a part problem to a causing station.

```
********************  Individual Route Name  *********************
                       Production Events

                 PN_21_HOUSING SERIAL NUMBER 1

Period:          30-SEP-1981  06:55:00  THRU  01-OCT-1981  06:55:00
Pallet:          1
-----------------------------------------------------------------
                          OPERATION      START          COMPLETE
DEVICE                    NUMBER         TIME           TIME

 LU:1                        1           07:00:00       07:15:00
 MC:1                        2           07:30:00       08:30:00
 MC:2                        3           09:00:00       09:30:00
 DV:1                        4           09:45:00       10:00:00
 LU:2                        5           10:05:00       10:15:00

*****************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered shift. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days avaiable (programmable).
- OPERATION NUMBER: Step number of operate command in the route.
- START TIME: Time when device is activated for the part located there.
- COMPLETE TIME: Time when device has completed activities for the part located there.

5.8 PALLET UTILIZATION REPORT

This class of report summarizes each pallet's use within the pallet group.

```
************************        Pallet        *************************
                          Production Summary

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 8.5
-------------------------------------------------------------------
PALLET GROUP

FIXTURE TYPE 1
                               ASSIGNED     UNASSIGNED     OUT OF SYSTEM
    PALLET    ROUTES           TIME         TIME           TIME
    NUMBER    COMPLETED        (HRS)        (HRS)          (HRS)

      1          15             6.0          0.5            2.0
      2          10             5.0          2.0            1.5
      3           0             0.0          0.0            8.5
      4           0             0.0          0.5            4.0
                 --            ----          ---           ----
TOTAL            25            11.0          3.0           16.0

                                 IN-SYSTEM UTILIZATION              61.1%
                                 AVERAGE ASSIGNED TIME PER ROUTE     0.4 HRS

FIXTURE TYPE 2
                               ASSIGNED     UNASSIGNED     OUT OF SYSTEM
    PALLET    ROUTES           TIME         TIME           TIME
    NUMBER    COMPLETED        (HRS)        (HRS)          (HRS)

      4           0             0.0          0.0            4.0
      5          10             3.0          3.0            2.5
                 --            ----          ---           ----
TOTAL            10             3.0          3.0            6.5

                                 IN-SYSTEM UTILIZATION              50.0%
                                 AVERAGE ASSIGNED TIME PER ROUTE     0.3 HRS

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- GROUP NAME: Thirty-two characters. Appears in alphanumeric order. Includes all related pallets in numerical order.

- ASSIGNED TIME: Time in which pallet is assigned to a given route.

- UNASSIGNED TIME: Time in which pallet is in the system but not assigned to a given route.

- OUT OF SYSTEM TIME: Any time when the pallet is not in the FMS.

- IN-SYSTEM UTILIZATION: Assigned Time/(Assigned Time + Unassigned Time).

- AVERAGE ASSIGNED TIME PER ROUTE: Assigned Time/Routes Completed.

5.9 CART UTILIZATION REPORT

This class of report summarizes cart use individually and collectively in an FMS.

```
*************************     Cart      *************************
                        Production Summary

Period:          30-SEP-1981  07:00:00  THRU  30-SEP-1981  15:30:00
Operating Hours: 8.5
-------------------------------------------------------------------
```

CART NUMBER	ASSIGNED TIME (HRS)	UNASSIGNED TIME (HRS)	CARRYING IDLE PALLET TIME (HRS)	OUT OF SYSTEM TIME (HRS)
1	6.0	0.5	2.0	0.0
2	5.0	2.0	1.5	0.0
3	0.0	0.0	8.5	0.0
4	1.0	7.5	0.0	0.0
5	3.0	3.0	2.5	0.0
	----	----	----	---
TOTAL	15.0	13.0	14.5	0.0

```
                          PERCENT UNASSIGNED TIME              30.6%
                          PERCENT CARRYING IDLE PALLET         34.1%

*******************************************************************
```

Explanation of Terms

- REPORT PERIOD: Shift, day, week. May be executed during the considered period. Three shifts available (programmable). Programmable Start and Complete for each shift. Seven days available (programmable).

- ASSIGNED TIME: Time in which cart is assigned to a given route.

- UNASSIGNED TIME: Time in which cart is in the system but not assigned to a route and not carrying an idle pallet.

- CARRYING IDLE PALLET TIME: Time in which cart is in the system but not assigned to a given route and carrying an idle pallet.

- OUT OF SYSTEM TIME: Any time when the cart is not in the FMS.

- PERCENT CARRYING IDLE PALLET: Carrying Idle Pallet Time/(Total Time - Out of System Time).

- PERCENT UNASSIGNED TIME: Unassigned Time/Total Time.

6.0 GLOSSARY OF FLEXIBLE MANUFACTURING SYSTEM TERMS

Revision 6
April 7, 1982

This glossary of FMS terms is intended to encompass all terms which are unique to the FMS field as well as terms in related fields which are particularly useful to FMS activities.

Suggestions for additions or changes to this glossary are always welcome.

BATCH SIZE	A quantity of items to be produced together, i.e., produced without a break.
CART	Vehicle used to transport pallets between stations.
CART SERIAL NUMBER	A unique number assigned to a specific cart.
CART TYPE	A distinct cart design.
CHIP TIME	Period of time in which a tool is cutting metal.
COMPUTER-AIDED DESIGN (CAD)	Use of computers in the design process.
COMPUTER-AIDED MANUFACTURING (CAM)	Use of computers in manufacturing systems.
COOLANT HANDLING SYSTEM (CHS)	System used to deliver, collect, move, and store cooling fluid.
DOWNTIME, MODULE	Period of time during which a module cannot process parts due to a failure in the module (a module's downtime plus up-time equals total time).
FIXTURE	Device used to hold a part such that its reference axes are in a defined ori-

entation with respect to the reference axes of a tool; may or may not be an integral part of a pallet.

FIXTURE, DUPLEX

A fixture designed to simultaneously hold two parts of the same type (number).

FIXTURE, PROGRESSIVE

A fixture which simultaneously holds two or more sides of the same part type, e.g., side one and side two.

FIXTURE SERIAL NUMBER

A unique number assigned to a specific fixture.

FIXTURE, SIMPLEX

A fixture designed to accommodate a single part number.

FIXTURE, TRIPLEX

A fixture designed to simultaneously hold three parts of the same type (number).

FIXTURE TYPE

A distinct fixture design.

FIXTURE, COMPOUND

Fixture designed to accommodate two or more part numbers, one at a time.

FIXTURE, SHARED

Fixture designed to accommodate two or more part numbers simultaneously.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

Computer-controlled configuration consisting of one or more modules and a materials handling system designed to machine more than one part number at low to medium volume levels.

GAUGING

The process of measuring a dimension or group of dimensions according to some standard.

GAUGING, ACCEPTANCE

Gauging performed upon the completion of all of the operations scheduled for a part, i.e., gauging performed at the output of a manufacturing system or subsystem used to determine if the completed part should be accepted, scrapped, or reworked.

GAUGING, IN-PROCESS

Gauging performed on partially finished parts while they are still in the manufacturing process.

GAUGING, ON-MODULE

Gauging performed at a module as an integral step in the processing of parts by the module.

GAUGING, TOOL

Gauging performed on tools to determine if they are within specified tolerance.

GROUP TECHNOLOGY

A method by which classification and coding schemes are used to identify and aggregate related part numbers so that design and manufacturing efforts can take advantage of their similarities.

HEAD-CHANGER

A module which can automatically inter-change multiple-spindle heads so that a variety of hole patterns requiring drilling/tapping can be produced.

LOT SIZE

A quantity of items to be produced at a given time.

MACHINE

Module at which a part can be altered.

MACHINING CENTER

A module which is capable of performing a variety of metal removal operations on a part including drilling, milling, boring, etc., usually under automatic control.

MATERIAL HANDLING SYSTEM (MHS)	System or systems used to move and store parts, as well as materials used in processing the parts (e.g., tools, coolant, wastes).
MODULE	A device which performs a process on a part at a station or group of stations.
MODULES, REDUNDANT	Identical modules in the same flexible manufacturing system.
NUMBER, DRAWING	Number assigned to an engineering graphic representation of a specific item; representation may be computer-based.
NUMERICAL CONTROL (NC)	A module or group of modules controlled by the direct insertion of numerical data.
NUMERICAL CONTROL, COMPUTER (CNC)	A single module operated in a numerically controlled mode by a single, dedicated digital computer.
NUMERICAL CONTROL, DIRECT (DNC)	Two or more modules operated in numerically controlled modes by a single digital computer.
OFF-QUEUE	Same as (QUEUE, OFF-SHUTTLE).
ON-QUEUE	Same as (QUEUE, ON-SHUTTLE).
OPERATION, CLUSTERED	A set of elementary operations simultaneously performed.

OPERATION, ELEMENTARY	Unit of work on a workpiece which, for purposes of scheduling, is normally not subdivided, e.g., drilling a single hole, rough milling a single surface, gauging a bore.
OPERATION, MODULE	Aggregation of all activities taking place during a single visit of a part to a module.
OPERATION NUMBER	Reference to a distinct operation on a distinct part setup.
OPERATION SEQUENCE	Ordered list of operations encountered by a part setup in a flexible manufacturing system.
OPERATION TIME, MODULE	Total time that a part spends at a module, including queueing time.
OPERATIONS, SETUP	Aggregation of operations performed on a part during a single setup.
PALLET	Device which serves as a standardized conveyance for the part in a flexible manufacturing system; may or may be an integral part of a cart.
PALLET SERIAL NUMBER	A unique number assigned to a specific pallet.
PALLET TYPE	A distinct pallet design.
PART	Workpiece processed by a flexible manufacturing system.
PART FAMILY	Generic family of parts based either on form (e.g., parts of rotation, prismatic parts) or manufacturing technology (e.g., stamped parts, milled parts).

PART HANDLING SYSTEM (PHS)	Network including carts, pathways, conveyors, chains, and storage areas for parts, fixtures, and pallets.
PART NUMBER	Distinct part design.
PART, PRISMATIC	A rectangular or box-shaped part, usually processed on a machining center.
PART PROGRAM	Set of instructions in the module control language and format necessary to perform the operations required to produce a given part.
PART PROGRAM BLOCK	Logical subdivision of a part program, e.g., the set of instructions for an elementary operation.
PART, ROTATIONAL	A part with at least one axis of rotation, usually machined on a lathe.
PART SERIAL NUMBER	Unique number assigned to a specific part.
PART SET	Set of all part numbers for a particular end-item.
PART SET, PRODUCTION	A subset of the system part set planned for production within the present planning horizon.
PART SET, SYSTEM	Set of all part numbers which can be produced by a given flexible manufacturing system without significant changes to its stations, tooling, part programs, etc.
PART SETUP	Entity consisting of a part mounted in a specific orientation on a fixture.

PART SIDE — A portion of a part which is processed during one fixturing (setup).

PART TYPE — Same as PART NUMBER.

PARTS, DESIGN-RELATED — Parts which have similar forms (e.g., parts of rotation, prismatic parts).

PARTS, MANUFACTURING-RELATED — Parts which undergo similar processing steps (e.g., stamped parts, milled parts).

PIECE-PART — A part which cannot be easily subdivided, an elementary part.

PRECEDENCE DIAGRAM, OPERATION — Diagram which shows, for a given part number, which operations must be performed prior to other operations, and which operations can be performed in any order.

PRECEDENCE DIAGRAM, PART SETUP — Diagram which shows, for a given part number, which part setups must be processed prior to other setups, and which setups can be performed in any order.

PROCESS PLAN — The detailed written instructions to be followed to manufacture a specific part.

PRODUCTION PLAN — Information required to produce a desired system output; information includes part numbers, quantities, tools, modules, schedules, etc.

PRODUCTION RATE MIX — Production part set and associated quantities, expressed as rates.

QUEUE, GENERALIZED — Same as (QUEUE, NONDEDICATED).

QUEUE, OFF-SHUTTLE	Pallet queue at exit from a module.
QUEUE, ON-SHUTTLE	Pallet queue at entrance to a module.
QUEUE, NONDEDICATED	Queue used both by pallets entering and pallets leaving a station.
REDUNDANT SYSTEM	FMS configuration in which any single element (e.g., tool, tool cluster, station, track intersection) can fail and the system part set can still be produced.
REDUNDANT TOOLING	Two or more identical tools in the same flexible manufacturing system.
REWORK	The process of remedying an incorrectly manufactured part by reprocessing it either in the normal manufacturing system or "off-line".
ROUTE, PART SETUP	Same as OPERATION SEQUENCE.
SCRAP	1. Fragments of stock removed from a part during manufacture. 2. A rejected or discarded part.
SEGMENT	A collection of elementary operations performed contiguously at a single work station.
SETUP	Entity consisting of one or more parts mounted in specific orientation(s) on a single fixture.
SHIP SET	Set of part numbers in the proper quantity required to assemble a particular complete end item.

SHIP SET, SYSTEM	That subset of a shipset which can be produced in a given FMS.
SIMULATION, FLEXIBLE MANUFACTURING SYSTEM	A computer simulation used to help in the design or analysis of an FMS, e.g., used to determine the relationships between system parameters such as production rate, number of modules, module types, etc.
STATION	A physical location where a part normally stops either to have an operation performed on it or to wait for clearance to proceed to the next station.
STATION, WAIT	A station at which a part or pallet waits, e.g., a berth in a queue.
STATION, WORK	A station where work is performed on a part.
TIME, ELEMENTARY OPERATION	Period of time required for the completion of an elementatry operation; does not include tool movement time.
TIME, MODULE BLOCK	Period of time during which a module is prevented from processing a part because a part cannot leave a work station due to a full off-shuttle queue and/or a blocked or failed parts handling system.
TIME, MODULE IDLE	Period of time in which a module is not processing a part because a part is not available; does not include module block time or part transfer times.
TIME, MODULE OPERATION	Period of time required by a module to complete a single operation on a

part; does not include part transfer times into and out of module.

TIME, PART TRANSFER
Period of time in which a part moves between a wait station (e.g., a queue position) and a work station or between two work stations.

TIME, TOOL CHANGE
Period of time required to replace one tool (or set of tools) with another; includes time to position tool for removal and time to reposition new tool.

TIME, TOOL MOVEMENT
Period of time between the performance of elementary operations in which a tool moves from one position to another; does not include tool change time.

TOOL HANDLING SYSTEM (THS)
System used to access and store tools and aggregates of tools.

TOOL SET, PART SET
Set of all tools required to produce a given part set on a given FMS.

TOOL SET, SHIP SET
Set of all tools required to produce a given ship set on a given FMS.

TOOL SET, MODULE
Set of all tools which can be accessed by a given module in its automatic mode of operation.

TOOL SET, SYSTEM PART SET
Set of all tools required to produce a given system part set on a given flexible manufacturing system.

TRACK
Network about which materials, tools, and/or gauges travel.

TRANSFER LINE
Group of work stations closely connected togeth-

er by an automated material handling system and designed for high-volume production of a single part number or very similar part numbers.

TRANSFER MACHINE	Same as TRANSFER LINE.
TRANSFER TIME	Time to transfer pallet between queue and station or between queue and track.
UP-TIME, MODULE	Period of time during which a module can process parts, i.e., it is not in the failed state (a module's up-time plus downtime equals total time).
UTILIZATION, MODULE	The quantity total time minus module idle time minus module downtime divided by the quantity total time minus module downtime.
WASTE HANDLING SYSTEM (WHS)	System used to collect, move, and store process waste.
WORK CONTENT	Time required by a module to perform a specific operation or set of operations on a given part.
WORKPIECE	A part which is in a module to be processed.

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8.1 THE NEED FOR KNOWLEDGE OF MACHINE TOOL ACCURACY

The accuracy of machine tools has been receiving increasing scrutiny by managers since the widespread acceptance of numerically-controlled machines. Before the introduction of NC, master machinists, each with years of experience and an intimate knowledge of his machine's idiosyncrasies and capabilities, could be counted upon to produce parts of the highest accuracy. Because the machinist's skill compensated for errors caused by the machine tool itself, these errors were invisible to the manager.

With the advent of NC, however, the master machinist was often removed entirely from production and replaced by a lesser skilled operator. This person usually was unable to compensate for the errors inherent in the machine, nor were these errors recognizable to the control system (in general). Machine, control, and tooling errors became visible in the finished product.

The introduction of FMS technology and "unmanned" machining has compounded the accuracy problem, for not only have the workers been removed from the machining area, but machining continues as finished parts are inspected elsewhere off the machine. The potential exists for producing a number of bad parts before corrective action can be taken, even if coordinate measuring machines are included in the line. To avoid this situation requires a shift in philosphy from post-process part inspection to pre-production (installation) machine inspection and preventative maintenance -- instead of measuring the part to see if the machine is functioning properly, measure, adjust, and maintain the machine to assure that the part is manufactured properly. FMS accuracy problems and their solutions are addressed in "Common FMS Accuracy Problems" on page 229.

This appendix briefly discusses the three major classes of machine tool errors: operational, mechanical, and thermal. Different methods of measuring them are presented. Three classes of solutions are discussed -- error avoidance, error compensation, and error correction -- and matched to the three classes of errors. Typical accuracy problems of an FMS and the need for preventative maintenance complete the appendix.

8.2 DEFINITIONS

It is essential to provide a common basis from which discussions of machine tool accuracy can begin. Definitions of "machine tool accuracy" and "machine tool error sources" should be a suitable basis. These definitions were developed by a working group, concerned principally with machine tool accuracy, that was part of the United States Air Force sponsored Machine Tool Task Force. For this discussion, when dealing with a machine tool and the parts produced using that tool, accuracy is defined as:

"The degree of conformance of the finished part to dimensional and geometric specifications".

All aspects of the machine tool system that contribute to this final part conformance are therefore the legitimate concerns of this accuracy study. When discussing the machine tool system itself, however, it is helpful to introduce a definition for deviation from accurate performance or error. Error is defined as:

"The difference between the actual response of a machine to a command issued according to the accepted protocol of that machine's operation and the anticipated response to that command."

8.3 CURRENT TRENDS IN MACHINE TOOL ACCURACY

To place the discussion of accuracy and errors in perspective, it is useful to consider the current status of machine tool accuracy and apparent trends for the future.

8.3.1 Current Status

1. The metalworking industry at large is just now learning what the individual skilled machinist always knew: instead of inspecting finished parts and rejecting the bad ones, it is much more economical and efficient to control the process so that the parts are made properly from the start. Similarly, the best method of error reduction is to prevent the error by eliminating its source. "Build it right the first time" is the motto. If this is too expensive or impossible, error measurement and compensation will be necessary to obtain "close to perfect" accuracy.

2. Few people are skilled in machine tool metrology and accuracy engineering. Training must be provided to enable workers to better understand how various machine tool errors cause parts to be out of tolerance, how to measure and correct those errors and how to make accurate parts.

3. Conventional workpiece metrology, which is mainly manual and traditional, will continue to be applied to production. However, coordinate measuring machines (CMMs) will find increasing acceptance in this area.

4. Machine tool errors are often difficult and tedious to measure using current methods. Simpler, less expensive, and less time-consuming methods are needed.

5. There is confusion and disagreement on accuracy specifications and testing. A major portion of all machine tools are sold without any accuracy specification or acceptance tests.

6. There is very little valid data on the cost of accuracy or the incremental cost of increased accuracy. There is widepsread belief that many parts have excessive accuracy requirements for their particular applications, but proof of these accusations is lacking.

7. A key to successful, accurate machining is the cutting tool: cutting tool geometry, cutting edge preparation, accurate position control of the cutting edge to the shank, proper inspection of new tools and accurate equipment for sharpening and presetting.

8.3.2 Trends

1. More complicated parts will be designed in the future, necessitating machines capable of movement in more axes than at present and presenting more difficult problems in alignment and testing.

2. Accuracy of geometry and/or surface finish will be an important aspect of more parts in the future. High accuracy machines will be required to produce higher performance products, less scrap, fewer rejects, less inspection effort, and reduced need for selective assembly. Many future parts may be difficult to inspect at all due to their complex geometry, emphasizing the need to make the part correctly the first time.

3. As many part measurements as possible will be done on-line, monitoring the process parameters and preventing system errors and rejects before they occur.

4. To improve reliability, contact gauges will be replaced with noncontact devices, such as those using optical effects, eddy currents or capacitance-change methods. Not only are noncontact gauges less likely to wear and often more reliable, but they usually also allow higher rates of inspection.

8.4 MACHINE TOOL ERROR SOURCES AND MECHANISMS

A manager is usually alerted to possible machine tool errors through the discovery of an error in the final form of a part. As illustrated in Figure 27 on page 219, this error, be it in size, shape, location or surface finish of a feature of the part can be the result of one or a combination of three broad classes of errors in the manufacturing process: (1) mechanical errors; (2) thermal errors; and (3) operational errors. Both mechanical and thermal errors can further be classified as attributable to either aspects of the machine or aspects of the part. Possible sources of errors in each class are listed below each class heading in Figure 28 on page 220. Where current knowledge permits, these sources are further described with respect to possible error mechanisms; the figure before a few of the sources is a key to the list of mechanisms provided below. Much research must still be done to clarify and describe each of these mechanisms; for the present, they are items to review while attempting to correct the production problem.

A second method of classifying these error sources is by the frequency of occurrence in the daily manufacturing process. Errors can be static (constant, continuous), occurring with approximately the same magnitude each time the manufacturing task is performed, or they can be dynamic (fluctuating, random), occurring with different magnitudes without pattern. This distinction is important, in that static errors are good candidates to resolve through compensation if the mechanism cannot be corrected, while dynamic errors must be avoided or corrected. The error sources from Figure 27 on page 219 are reclassified in Figure 29 on page 225. Note that some sources are listed in both classifications; in some cases (often where manual intervention occurs), the error source can have both static and dynamic components.

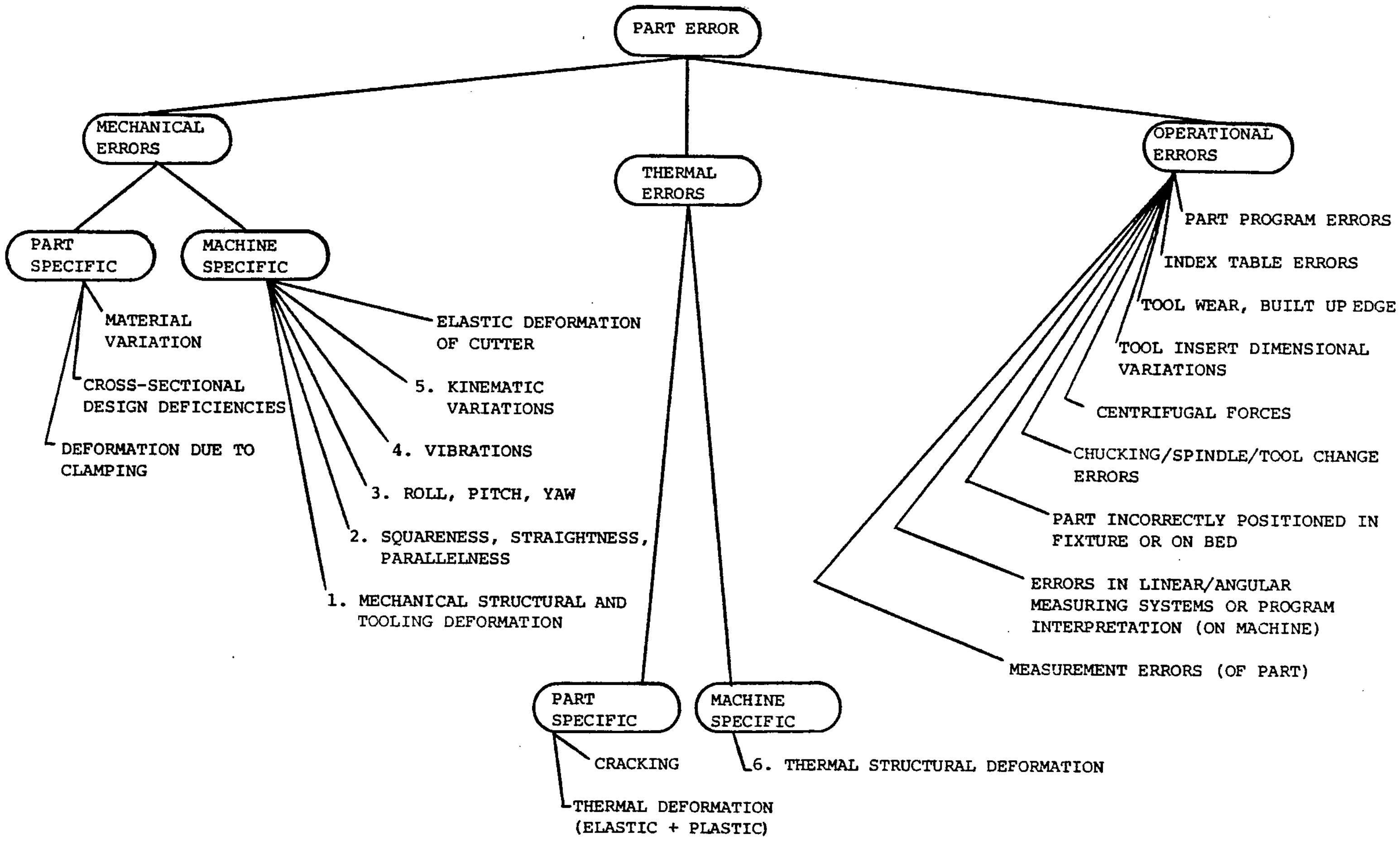

Figure 27. Error Sources

Error Source	Apparent Mechanisms
1. Deformation of Structure, including tooling mounted on machine table (due to mechanical forces)	a. Weight of components.
	b. Insufficient static design features.
	c. Improper (or insufficient) stress relieving in the machine parts.
	d. Redundant kinematic constraints on the machine parts, especially when using a concrete base to provide additional machine stiffness.
	e. Weight of part/pallet/fixture, especially at limits of carriage travel (insufficiently designed support).
	f. Incorrect design for required stiffness.
	- Stresses developed during clamping of the part on the pallet or of the table to the slideways.
	- Stresses due to cutting force.
	- Stresses due to drive mechanisms -- torque, thrust, etc.
	- "Memory" errors -- after removal of stress, the structure requires time to return to its designed state.

Figure 28. Error Source Mechanisms (Part 1 of 5)

Error Source	Apparent Mechanisms
2. Squareness, Straightness, Parallelism (linear relationships between axes)	a. Incorrect fabrication of ways (geometric form errors). b. Structural deformation due to mechanical forces. c. Structural deformation due to thermal forces. d. Improper measuring techniques.
3. Roll, Pitch, Yaw of Each Axis (rotational relationships between axes)	a. (a)-(d) above. b. Squareness, straightness, parallelism.

Figure 28. Error Source Mechanisms (Part 2 of 5)

Error Source	Apparent Mechanisms
4. Vibration	
a. Forced vibration (most important in fine grinding, turning, boring); most serious when vibrational frequency is close to natural resonant frequency of the equipment.	a. Mechanical unbalance of rotating members - flywheels, spindles, gears, etc.). b. Electromagnetic unbalance of electrical motors and pumps. c. Inaccuracies in bearings. d. Pulses in hydraulic pressure. e. External vibrations. f. Tooth impacts of cutter. g. Incorrect tool clamping. h. Wear land on tool flank.
b. Self-excited vibration (chatter)	a. Too thick a chip (excessive depth of cut). b. Relative motion between the tool and workpiece conforms to the surface undulation left by the cut in the previous tool path. Resultant variation in tool force produces a secondary vibration. If this is of sufficient magnitude, the natural frequency of the machine may be excited. This vibration is due to insufficient dynamic rigidity at the natural mode. c. Periodic chip formation (interrupted cuts).

Figure 28. Error Source Mechanisms (Part 3 of 5)

Error Source	Apparent Mechanisms
5. Kinematic Variation (errors between sets of moving axes) - Rotation/rotation. - Translation/rotation. - Translation/translation	a. Machine way errors. b. Spindle slope and runout. c. Gear cutting axis lead-screw errors (backlash, wind-up). d. Angularity, parallelism errors. e. Measurement errors. f. Straightness, roundness errors. g. Electric and electronic control errors. h. Installation errors.

Figure 28. Error Source Mechanisms (Part 4 of 5)

Error Source	Apparent Mechanisms
6. Deformation of Structure (due to thermal forces). In steel - 0.0007"/foot expansion for 10 degrees F increase:	a. Spindle and associated bearing fluctuation. b. Heat from internal sources: - Motor - Transmission and hydraulic oil - Pumps - Guideways (friction) - Bearings, power take-offs, etc. - Electrical systems c. Poorly designed expansion joints, heat sinks, etc. d. Heat from external sources: - People - Local environment - Cutting tool and coolant (sinks and hot spots). e. Speed and duty cycle of equpment. f. Improper or slow removal of chips.

Figure 28. Error Source Mechanisms (Part 5 of 5)

	Static	Dynamic
Part-Specific Mechanical Errors:	Material variation. Cross-sectional design deficiencies. Deformation due to clamping.	Material variation. Deformation due to clamping.
Machine-Specific Mechanical Errors:	Elastic deformation of cutter kinematic variations. Roll, Pitch, Yaw. Squareness. Straightness. Parallelness. Mechanical, structural and tooling deformation.	Elastic deformation of cutter vibrations.
Part-Specific Thermal Errors:	Thermal deformation	Cracking. Thermal deformation.
Machine-Specific Thermal Errors:	Thermal, structural deformation.	Thermal, structural deformation.
Operational Errors:	Part program errors. Index table errors. Centrifugal forces. Errors in linear/ angular measuring systems or program interpretation (on machine).	Index table errors. Tool wear, built-up edge. Tool insert dimensional variations. Chucking/ Spindle / Tool change errors. Part incorrectly positioned in fixture or on bed. Errors in linear/ angular measuring systems or program interpretation (on machine). Measurement errors (of part).

Figure 29. Classification of Errors by Nature

It is difficult to discuss the relative importance or magnitude of one class of error over another. In general, operational errors, which are usually dynamic, represent the largest (in magnitude) error sources, but with careful machining and shop practices are also the easiest to avoid and correct. Thermal and mechanical errors are, in general, of the same magnitude; however, since the majority of mechanical errors are static, they can be compensated for or corrected (whichever is easier) and made invisible to the piece part. Thus, thermal errors emerge as the most difficult error source to deal with, especially when manufacturing close tolerance parts where small random deviations are most evident (tolerances less than or equal to 0.001 inch).

8.5 TOOLS FOR DETERMINING MACHINE TOOL ACCURACY AND THEIR APPLICABILITY

Before errors can be corrected, their magnitude and influence must be measured. There is a broad range of measuring tools available to determine machine tool accuracy; from a taut piece of music wire to a sophisticated laser interferometer. Although "high technology" is making its impact felt on the selection of measuring tools and the reliability of the machine accuracy determined by these tools, the measurement process is still long and arduous. There is no substitute for painstaking care in the setup of measuring equipment and in the performance of the testing procedure. There is, of course, a range in the ease of use of the test equipment; it is also reasonable to assume that some tools are better suited for examining certain features of the machine tool than others.

With this in mind, Figure 30 on page 227 is organized by the feature being measured. The test equipment recommended for each feature is then listed in order of ease of setup and use from fast and simple to very long and tedious. In addition, the resolution and maximum accuracy range is listed to provide a means by which to estimate the tradeoffs involved when choosing one tool over another. "Resolution" is the smallest increment a measuring device is capable of measuring. "Accuracy" is a quantitative measure for each measuring tool of the degree of conformance of a feature's measurement to the actual size of the feature. All of the tools listed can be used for thermal testing in conjunction with thermometers. Thermal testing is more simply accomplished, however, by using dial indicators or electronic indicators against points to be measured on the machine and tracking the displacements as a function of machine duty cycle temperature and time using a stripchart recorder.

Another "tool" that is often discussed with respect to machine tool accuracy is the cutting test or "tryout". It is common practice to cut a few pieces on a machine, measure them, and then assess the accuracy of the machine. While suitable for gross evaluations of accuracy, this method has a number of shortcomings. First, it is difficult to separate machine deficiencies from problems with the cutting tool, the fixture, or the operator. Second, those errors that might be attributable to the machine are composites of both static and dynamic errors -- without repeating the test numerous times, the dynamic errors cannot be isolated. Not compensating for the static component or compensating for the entire error as

	Resolution	Accuracy	Range
POSITIONING ACCURACY:			
Line Scale Tool (with microscope)	0.002 in		35 ft
Laser Interferometer	0.000001 in	±0.000003 in/in	300 ft
Step Gauge (with indicator)	0.375 in to 1.000 in	±0.000004 in/in	0.5-4 ft
ROTATIONAL ACCURACY (SMALL ANGLE, PITCH AND YAW):			
Laser Interferometer	0.1 sec.	±0.1 sec.	±50 min.
Autocollimator with mirror	range/1000	±0.1 sec.	10 min.- 10 sec.
Electronic Level	0.5 to 0.2 sec.	±1.0 sec.	±1 degree
Spirit Level	1.0 sec.	±1.0 sec.	10 min.
ROTATIONAL ACCURACY (LARGE ANGLE):			
Autocollimator with optical polygon	40 degrees	±1.0 sec.	360 degrees
Grating Scale	1.0 sec.	±1.0 sec.	360 degrees
Shaft Encoder	0.6 sec.	±1.8 sec.	360 degrees
SQUARENESS OF AXES:			
Set Squares	0.000001 in	±0.000005 in/in	5 ft
Laser with Pentaprism and Wollaston Prism	0.000001 in	±0.0000005 in/in	100 ft

Figure 30. Measuring Tools and Their Applicability (Part 1 of 2)

STRAIGHTNESS/FLATNESS:			
Straightedge with Dial Indicator	0.000001 in	±0.0000005 in/in	5 ft
Taut Wire			
Microscope	0.000080 in	N/A	N/A
Electronic	0.0000005 in	N/A	N/A
Alignment Telescope	0.000080 in	±0.000005 in/in	300 ft
Laser with Wöllaston Prism	0.000001 in	±0.0000005 in/in	100 ft
PARALLELISM:			
Straightedge with Dial Indicator	0.000001 in	±0.0000005 in/in	5 ft
Laser	0.000001 in	±0.0000005 in/in	100 ft

Figure 30. Measuring Tools and Their Applicability (Part 2 of 2)

though it were static can still result in producing bad parts. Third, because the errors found are composites, it is difficult to determine the individual error sources or their mechanisms and correct them.

The cutting test does have an advantage over all of the other measuring tools discussed, however, in that if the cutting tools, fixtures, etc., are performing correctly, this is the only test that can indicate what composite accuracy the machine is capable of in production. In light of its disadvantages, when using this approach, the results it provides must be reviewed very cautiously before a machine is rejected.

8.6 ERROR SOLUTIONS

There are three broad classes of solutions for machine tool errors: error avoidance, error compensation, and error correction. In general, error avoidance is the easiest and least costly method of eliminating human or operational errors. Error avoidance usually consists of maintaining good shop and machining practice, maintenance discipline, and an awareness of how fixture design, poor tool setting, or other actions can effect machine and part accuracy. Since operational errors are by far the largest contributor to part error, error avoidance can lead to significant improvements in part accuracy at very little expense in time or effort. Often, further exploration of machine tool errors is unnecessary, for error avoidance reduces the magnitude of the part errors to within normal tolerance bands. This is especially true when producing parts on relatively new equipment, where the machine's design and installation are generally more than adequate to limit inherent mechanical and thermal errors to well within normal tolerance limits.

When machining high-accuracy parts, however, it is unlikely that error avoidance will remove all of the errors in the part. Very detailed examination of the machine tool is required, using some of the tools discussed in this section to attempt to determine the mechanical and thermal error sources, their magnitude, and their mechanisms, if possible. After performing these tests over time, the error sources can be segregated into two categories: static errors and dynamic errors. Although often of similar magnitude, static errors are significantly easier to work with than dynamic errors. Two classes of solutions are available for static errors: error compensation and error correction. The choice of solution will depend on the nature of the error and which solutions will be best suited to it.

For example, if a machine tool had a bed that sagged slightly at one end when the table moved over it, and only one axis was effected, it might be possible to program offsets in another axis to compensate for the sag while cutting. If, however, all three slide axes were affected, an offset table would be extremely difficult to generate, and so the support of the bed would have to be corrected. Conversely, if a lead-screw had some pitch error, it would probably be easier to change it (correct the error), even though a compensation table could be developed.

Dynamic errors, usually from thermal error sources, are the most difficult to handle, requiring either correction or acceptance. Little currently exists in real-time instrumentation that will allow "adaptive control" for these errors, so compensative solutions generally are of little help. After elimination of static errors, though, the effects of dynamic errors are usually minimal except on the most accurate of parts.

The classes of solutions discussed can be time-phased, just as the installation of an FMS or other machine tool will be. Before installation, begin error avoidance by reviewing fixture and tool design, tool setting methods, and general shop discipline to maintain a high level of accuracy in operational areas. During installation, analyze the machine, determine the class and magnitude of the errors found, and either apply error compensation or correct the error. Once satisfied that the machine is as accurate as necessary or economically feasible, maintain that level of accuracy during operation through the implementation of a rigorous preventative maintenance program and adherence to it.

8.7 COMMON FMS ACCURACY PROBLEMS

Most of the accuracy problems in an FMS are common to those of stand-alone NC machines, because FMSs are simply a number of standard NC machines, connected by an automated material handling system. These accuracy problems are aggravated by the lack of constant attention from a machine operator, who could realign parts in a fixture, tweak cutting tools, etc., to compensate for small machine and operational errors.

As discussed, a well defined error avoidance program should be developed before the FMS is installed. The machines and material handling system interfaces should be analyzed and aligned during installation, when as many of the mechanical and thermal errors as possible should be corrected or compensated for. A preventative maintenance program should be developed in conjunction with the vendor and maintenance departments to try to maintain the accuracy at the level realized just after inspection.

Machine tool vendors often offer special "accuracy" packages, permitting higher machine accuracy than normal through the use of special measuring systems, adaptive control, redesign of the machine, and so on.

The most common errors in an FMS occur at the interfaces of equipment or interfaces to humans. Misalignment of the part on the fixture, the fixture on the pallet, and the pallet on the machine are additive and can result in a large error at the part/spindle interface. These alignment problems usually stem from wear of the location devices, chips and coolant residue at the interface, or human error, and can be controlled through preventative maintenance and shop cleanliness. In addition, it is recommended that the fixtures be permanently attached to their pallets, to reduce the potential for misalignment.

Another common problem is variation in preset tools or missetting of the tools. In either case, training and discipline can have a significant impact. Cutting tool errors also can result from tool wear, built-up edges on the cutting surface, or chucking errors between the tool shank and spindle which affect tool alignment.

Minor machine crashes, usually caused during startup or after fixing a failure by operators who do not have sufficient experience in running an FMS, can create a more difficult problem. A master part and pallet combination should be developed for use in the preventative maintenance program, and can be used after crashes as well as during periodic maintenance to check the alignment of any machine. This is accomplished by tracing the part with a probe and determining the errors. When misalignments are discovered, a decision must be made to compensate for it or correct it. Often, the machine will then be taken out of service and maintenance personnel will realign the machine using the same procedure which was used when the equipment was installed.

Most error sources are mechanical or human. Experience has shown the electronics associated with an FMS to be quite reliable.