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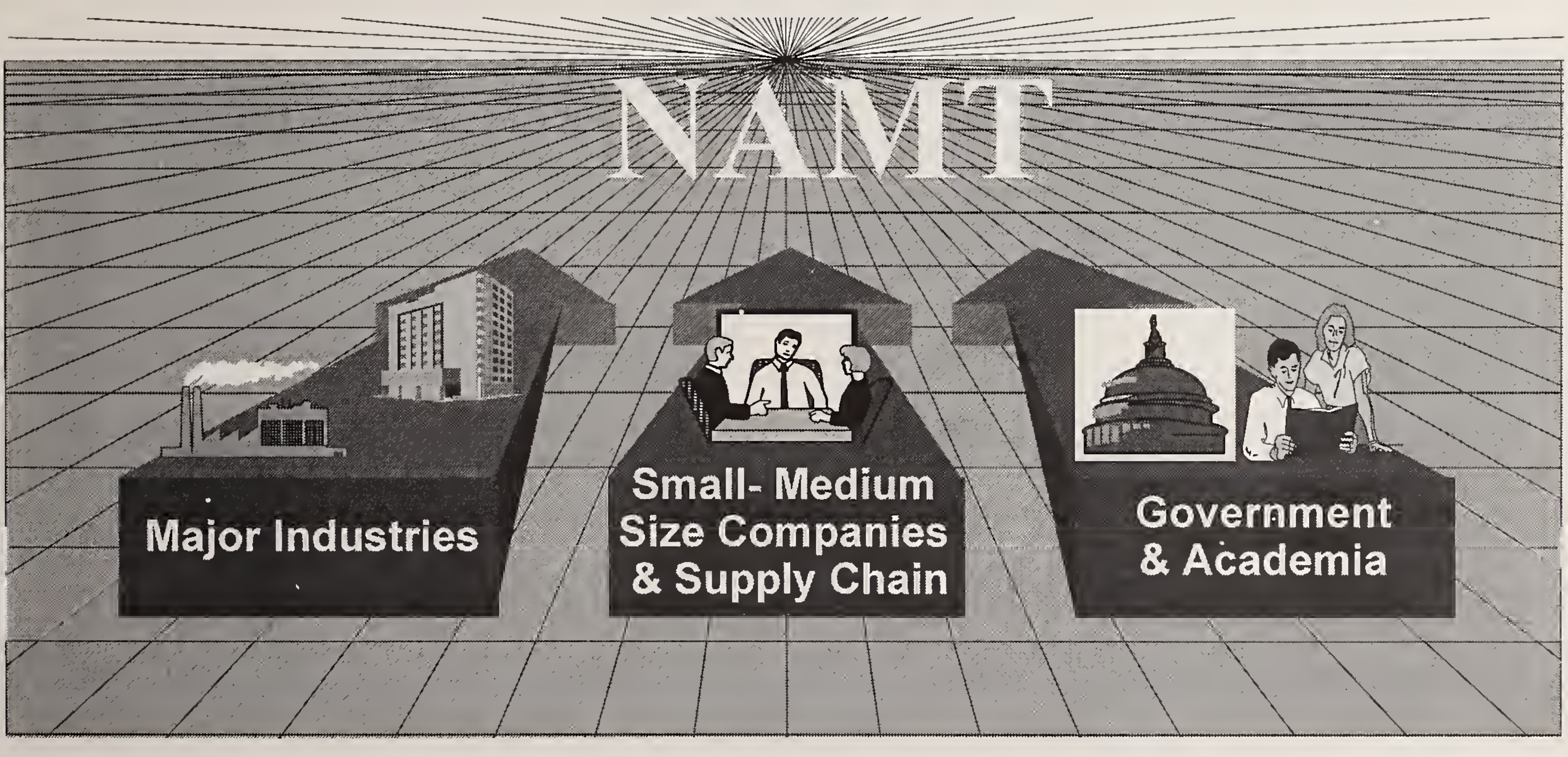
Conceptual Design Plan for the National Advanced Manufacturing Testbed

Merrill M. Hessel



A Distributed and Virtual Manufacturing Testbed

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PREFACE

This plan is a result of several stages of testing the concept of a distributed and virtual manufacturing testbed with various private sector and government organizations. An initial prospectus defining a National Advanced Manufacturing Testbed (NAMT), "A Distributed and Virtual Manufacturing Testbed," was developed by a management team of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST). During the months of September through November 1994, the ideas were alpha-tested in face-to-face interviews with over 25 senior executives from industry and government. As the ideas for the NAMT were refined, an invitation-only Workshop was held in December 1994 for industry and government senior executives. The purpose of this workshop was to define the benefits, actions, possible projects, and scenarios for such a testbed. The proceedings of this workshop are available upon request. It was the consensus of the Workshop participants that a dedicated industry-government team (IGT) should be formed to develop a NAMT plan.

An IGT was assembled in February 1995, and developed a draft version of the plan which was then critically reviewed by a "Red Team," consisting of 34 representatives of major manufacturers, suppliers, information providers, consortia, manufacturing technology centers, government agencies and a university research institute. The many participants who contributed to the various phases of formulation of the NAMT Plan are listed in Appendix A.

This draft NAMT plan is a revision based upon the "Red Team" comments. It will be submitted to the appropriate industry and government management for approval, initiation and/or participation in the NAMT.

This conceptual document provides the basis for participation decisions in the National Advanced Manufacturing Testbed Program.

A VISION OF THE FUTURE MANUFACTURING ENVIRONMENT

The manufacturing environment of tomorrow will consist of multiple organizations functioning as parts of integrated enterprises. The enterprises will design and simulate both products and manufacturing processes using distributed and virtual manufacturing (DVM) technologies. At the disposal of these enterprises will be a set of geographically distributed resources that include specialized simulation tools, design tools, machines and personnel to fabricate, to procure and to maintain products. All phases of the product life-cycle, manufacturing processes and integrated product and process design will be included, enabling businesses to quickly and efficiently design and manufacture products of high quality and low cost.

NAMT MISSION

To achieve this vision, industry, universities and government are working *independently* on various aspects of a distributed and virtual environment. The mission of the National Advanced Manufacturing Testbed (NAMT) program is to accelerate the development of a comprehensive, integrated set of DVM capabilities. To accomplish this, the NAMT will provide a unique combination of diverse physical facilities and personnel from industry, academia, NIST and the National Laboratories to actively coordinate and integrate the results from individual efforts. Each of these organizations will contribute technical expertise in manufacturing, standards, measurements, testing and validation methodologies. Specific industry-defined projects will be used to anticipate, address, test and demonstrate the DVM technologies needed to integrate and provide interoperability among suppliers, vendors and manufacturers.

NAMT OBJECTIVE and GOALS

The **objective of the NAMT** program is to establish and operate a distributed, multi-node, multi-project testbed among industry, government agencies and universities. This testbed will facilitate coordination between individual projects and foster development and demonstration of industry-defined scenarios which advance DVM technologies to support integration and interoperability among suppliers, vendors and manufacturers. The goals of the NAMT program are to:

- define, demonstrate and test integration and interoperability standards;
- improve supplier chain integration;
- facilitate access to specialized manufacturing resources (machines, systems, software tools and technical expertise);
- cooperate and coordinate with related programs to identify and fill voids, leverage projects and avoid duplication;
- provide a testbed to serve as a national framework for demonstrating and testing new DVM concepts;
- determine robustness and ability to scale DVM solutions; and,
- reduce risk in development and deployment of DVM technologies.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The National Advanced Manufacturing Testbed (NAMT) Program provides a collaborative context for helping U.S. manufacturers achieve a competitive advantage. It is a national industry-government teaming program designed to leverage private sector and federal investments, expertise and facilities to accelerate the development and implementation of technologies for distributed and virtual manufacturing (DVM). Specific industry-defined projects will be used to anticipate, address, test and demonstrate the DVM technologies needed to integrate and provide interoperability among suppliers, vendors and manufacturers. The NAMT program is facilitated by the Department of Commerce and managed through a program office hosted by the NIST Manufacturing Engineering Laboratory.

NAMT brings advanced technologies and organizations together to provide an environment to validate and deploy more quickly the new technologies which are necessary to create truly effective DVM. The testbed acts as a testing site and a central focal point for organizations looking for better ways to do business in the future.

NAMT is an industry-driven partnership among large, medium and small manufacturing enterprises, government and academia. It provides value added components to U.S. manufacturing enterprises by: 1) lowering the cost of collaboration by providing an infrastructure and strengthened links for technology transfer, 2) contributing to the development and validation of DVM related standards 3) focusing the number and direction of DVM projects to assure the availability of a sustained core of resources and 4) coordinating with related efforts throughout the world.

The **objective of the NAMT** program is to establish and operate a distributed, multi-node, multi-project testbed among industry, government agencies and universities. This testbed will facilitate coordination between individual projects and development and demonstration of industry-defined scenarios which advance DVM technologies to support integration and interoperability among suppliers, vendors and manufacturers. The goals of the NAMT program are to:

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- cooperate and coordinate with related programs to identify and fill voids, leverage projects and avoid duplication;

- provide a testbed to serve as a national framework for demonstrating and testing new DVM concepts;
- determine robustness and ability to scale DVM solutions; and,
- reduce risk in development and deployment of DVM technologies.

The NAMT program operates to minimize the cost and maximize the benefit of collaborative development, evaluation and deployment of DVM systems. The program will operate under a joint industry-government management structure. This structure assigns responsibility for program implementation and realizes the broadest possible industry representation while meeting the NAMT mission.

Participants define, select and execute industry-driven projects that demonstrate and validate distributed and virtual manufacturing technology. The value of the NAMT program will be measured by industrial participation and by the successful execution of the NAMT projects. The plan provides a project initiation and screening process based on projects submitted by industry and NIST.

The NAMT will consist of geographically distributed and network-linked nodes, physical resources such as facilities and the technical expertise of the participants. Nodes specialize in an aspect of enterprises that NAMT integrates for the design, development, manufacturing and distribution functions to produce a product or to offer services. Nodes will be located at private sector sites, government facilities and universities.

The NAMT concept represents a new way of doing business since it is not in itself a direct funding source for projects. Rather, NAMT will provide a significant set of resources and close linkages to industrial and government agency funding sources. NAMT is designed to be a $13 - 25 M per year joint industry-government program. It is the aim of this effort to leverage resources and coordinate with all identified DVM related efforts to the extent practical.

The NAMT program creates a context for government and industry investments in technologies relevant to DVM. NAMT projects do not replace nor duplicate existing programs, but provide a complementary set of industry-driven core programs and services.

In the final analysis, the value of NAMT will be judged by the extent of industry participation. This planning document is a first step at the start of the journey.

Chapter 1. NAMT BACKGROUND

Starting in the 1980's the Manufacturing Engineering Laboratory (MEL) of the National Institute of Standards and Technology (NIST) developed and managed a flagship program, the Automated Manufacturing Research Facility (AMRF). Hundreds of industry personnel and staff from other institutions came to NIST to work on research and development projects to advance the state-of-the-art of manufacturing and to transfer technology to individual companies.

Based on MEL's focus on standards and measurement and the AMRF experience, a planning team of Division Chiefs and the Director of MEL has developed an initial prospectus for a National Advanced Manufacturing Testbed (NAMT). The focus of this prospectus was to develop a testbed for DVM technologies. The planning team had extensive face-to-face discussions with over 25 senior executives from U.S. manufacturing industry and other organizations.

Based on the positive response to the idea of a DVM testbed, a workshop for a limited number of industry and government senior executives was held in December, 1994. This workshop focused on the industrial need for such a testbed, the potential benefits of developing a NAMT program, the actions necessary to achieve the benefits and the possible scenarios or projects.

As an outcome of this workshop, an industry-government planning team (IGT) was assembled to develop a formal NAMT plan. An iterative process was employed which built around information needs, action categories and multiple write-review cycles. A special effort was undertaken to develop criteria for specific projects and review a set of potential initial projects that could be used as templates for NAMT focused efforts.

A version of the NAMT Plan was sent to a "Red Team" for review. The "Red Team" was composed of senior personnel from 11 major manufacturers, 2 major industrial suppliers, 1 information provider, 3 industry consortia, 3 technology centers focused on manufacturing, 6 government agencies, 1 university and 1 manufacturing consultant. There were also 6 "Red Team" reviewers representing three operating units of NIST. This draft NAMT plan is a revision based upon the "Red Team" comments.

Appendix A lists all the personnel who have contributed to the formulation of this plan.

Chapter 2. INDUSTRY NEEDS, NAMT SCOPE AND BENEFITS

This chapter discusses the needs of U.S. industry relative to the vision for manufacturing stated at the beginning of this document and the role of DVM in that vision. The scope of NAMT is defined with respect to these needs and the benefits from NAMT participation are described.

2.1 Industry Needs

Based on direct discussions with senior executives from industry, published reports, industrial forums and activities and the NAMT Workshop held in December 1994, it is clear that to be globally competitive in the 21st century manufacturing environment, industry needs the ability to rapidly introduce affordable, quality products that customers want. This requires a manufacturer to quickly assemble a team of best practice suppliers, contractors and partners to assist in the design, production, marketing and support for the product.

From the NAMT planning process, executive interviews, workshops and "Red Team" feedback, three major roadblocks to successful implementation of this environment have been identified. These are:

- the inability to quickly integrate and interoperate the technical and business systems of the manufacturer with the customers, suppliers and partners;

- the inability to rapidly prototype and evaluate both the product and processes to manufacture that product; and

- the inability to rapidly locate customers and select optimum suppliers and/or partners.

The first two roadblocks are directly addressed by the NAMT goals of

- defining, demonstrating and testing appropriate integration, interoperability and related standards;

- improving supplier chain integration through DVM technologies; and

- facilitating access to specialized manufacturing resources (machines, systems and technical expertise).

The third roadblock identified may be partially addressed by the information repository planned for the NAMT. The roadblocks identified above reflect the priorities of a number of industry leaders. *American industry needs the NAMT to support migration toward a distributed and virtual manufacturing enterprise at the* *national level*. No single commercial enterprise has the resources to develop such a solution. This is reiterated in a quote from Dr. Joseph Erkes, GE Corporate Research and Development, that was published in the June 1994 Issue of "Manufacturing Review":

> ". . . when we look to the software tools we need to make it happen (i.e., a supplier of world-class products that are first to market) we face a tower of Babel. The software systems needed to design and manufacture products are large, and getting bigger and more unwieldy with each new release . . . and few speak to one another except in their own proprietary tongues. As a result, most of American industry has deployed heterogeneous suites of software tools where humans provide the integration and coordination. These individualistic systems are difficult to maintain, expensive and above all lack the agility to respond to the challenges of endless change in the nineties and beyond. Although many interesting and valuable technical solution fragments are emerging, consensus on integrated solutions and the protocols and standards needed to support them are growing at a pace that might charitably be described as glacial."

NAMT is a program that will provide a central focus to coordinate and leverage the projects and partial solutions in existence and under development within American industry. Standards that facilitate the interoperability of systems within environments are critical to the integration of enterprises. NAMT will promote the development and implementation of these standards.

2.2 NAMT Scope Relative to Industrial Needs

As an initial scope, NAMT will focus on the discrete manufacturing industry segment of the national manufacturing environment and the problems of interoperability and integration of systems used for product and process design and manufacturing control. NAMT will provide access to specialized manufacturing resources (machines, systems and expertise) resident at its core nodes.

As NAMT evolves, participation will increase which will expand the program's scope to more comprehensively address American manufacturing needs as experienced within the national manufacturing environment.

2.3 Benefits of NAMT

As an industry-driven national effort, the NAMT is in position to provide a unique national focal point for the advancement, refinement and integration of DVM technologies. NAMT is *unique* in two important aspects.

- NAMT is designed to be a nationwide, open access testbed. It is hosted by NIST, an organization that is globally recognized in the areas of standards, measurements and control systems.

- The National Laboratories at Sandia and Oak Ridge have major facilities and technical expertise in rapid prototyping, complex machining and robotic systems that will be available to allow participants to demonstrate and validate specific DVM technologies.

As an open testbed, product development ideas from many sources can be explored, developed and verified. Participants can assess the robustness and ability to scale DVM solutions. They can improve the integration of supply chains. Through a series of projects (examples of which are discussed in Chapter 5 and Appendix C) NAMT project participants will identify and develop the necessary interoperability standards. The results of this work will allow suppliers with suitable technical expertise to easily join and form virtual enterprises to integrate their systems, procedures and methodologies.

Using DVM techniques coupled with rapid prototyping, participants can easily and quickly validate product designs. They will also be able to model manufacturing processes, test alternative configurations and realistically portray a product's look-and-feel.

NAMT will provide U.S. Industry with a resource to access advanced manufacturing information and capabilities that reside in widely scattered locations connected through a communications network. U.S. Industry understands the necessity to manage supplier chains and this national testbed will offer major facilities to support DVM projects with this focus. NAMT will provide a focal point for U.S. Industry to apply new tools and techniques in demonstration situations that can be tailored to specific applications of interest. At the start of this program three nodes strategically located in the nation will immediately offer state-of-the-art capabilities. Subsequently, NAMT will add to its capabilities as driven by the needs and commitment of industry.

Chapter 3. NAMT Management and Operations

The NAMT management and operations concepts will reduce the barriers to collaboration and enable industry, government and academia to cooperatively build this national program. The concepts described in this chapter include how to participate in the NAMT program, the proposed management structure and how NAMT will operate.

3.1 Program Participation

NAMT is built upon the premise that cooperation is required for the timely achievement of DVM benefits across the broad manufacturing spectrum, from large corporation to small supplier. Effective cooperation will assure that a critical core of resources are made available to priority problems.

NAMT will be organized around an initial set of core nodes with significant resources available for NAMT. Nodes will contain some or all of the following resources: simulation tools, design tools, specialized manufacturing equipment and staff to support the specific aspects of the manufacturing process and production. The initial organizations committed to provide core nodes are the Department of Commerce National Institute of Standards and Technology and the Department of Energy National Laboratories at Sandia and at the Oak Ridge Centers for Manufacturing Technology. Interest has also been expressed by individual corporations, other government agencies, academic institutions, associations and industrial consortia in participating in the NAMT program.

NAMT will not attempt to replace nor duplicate existing programs. Rather, it will provide a basic program and set of services to enable industry, government and academia to leverage existing activities and to collaborate more effectively in the development, validation and deployment of DVM capabilities.

Stakeholders are expected to include machine tool builders, manufacturing supply chain participants, manufacturers of products, computer hardware and software vendors, software system application developers and many others.

The NAMT program structure will allow participation in several forms. There are core node participants, project node participants, project members and open participation.

3.1.1 Core Node Participation

The initial commitment for core node participation is expected to be three to five years to provide continuity of assets as NAMT matures. Each core node will bring significant resources to the NAMT in the form of facilities, manufacturing equipment, technical expertise and electronic communications infrastructure. This initial aggregation of existing private and public investment will provide a sustaining set of resources which will enable early participation by small-to-medium enterprises (SMEs) as NAMT attracts additional core participants.

Core node participants are eligible to participate in the governance of NAMT as members of the Executive Steering Panel, the body charged with setting policy and strategic direction for the program, which will be described later in this chapter.

The three organizations committed to NAMT as core nodes have identified the following resources for the NAMT and have indicated that additional resources could be available.

NIST Manufacturing Engineering Laboratory:

- Octahedral Hexapod Machine
- Advanced Manufacturing Systems and Network Testbed (AMSANT)
- High accuracy coordinate measuring machines (CMMs)
- Open architecture control systems for factory equipment
- Virtual Collaborative Environment Laboratory
- National PDES Testbed

Oak Ridge Centers for Manufacturing Technology:

- Manufacturing Skills Demo Campus (Fully Outfitted Machine Shop)
- Concurrent Engineering Center (Process & Product Simulation Capability)
- High accuracy CMMs

Sandia National Laboratories (DOE):

- Robotics Research Facility
- Rapid Prototyping Facility

Additional capabilities are expected to be added at the commencement of NAMT. Several industrial organizations have already indicated a commitment, and several others, as well as universities, are expected to commit after publication of this document. A key advantage to the participants of NAMT is the leverage achieved from the accessibility to core node facilities and technical expertise.

3.1.2 Project Node Participation

Any organization can submit projects or scenarios that are appropriate for the NAMT. A NAMT project node participant must physically house a node, but is committed for the duration of its specific project only. As such, project node organizations may contribute to the development of the NAMT Strategic Plan, have access to core node resources, have access to NAMT services as defined in the operations section of this chapter and have the potential to reduce development and implementation risks. The concepts of NAMT nodes and NAMT projects are described in Chapters 4 and 5 of this document, respectively.

3.1.3 Project Member Participation

Any potential project member may propose projects or scenarios that are appropriate for the NAMT. Participation in NAMT as a project member means that an organization is an active member collaborating in the conduct of a NAMT project, yet the organization does not house a NAMT node.

As a NAMT project member, an organization is committed to NAMT for the duration of its specific project only. As such, project member organizations may contribute to the development of the NAMT Strategic Plan through their respective project node organizations, have access to core node resources, have access to NAMT services and have the potential to reduce risks.

3.1.4 Open Participation

NAMT will provide programmatic information to the public, as well as public domain information about its projects, through existing electronic communication systems such as the World Wide Web. Users of these systems will have free access to this information.

3.1.5 Participation Requirements and Benefits

Table 3-1 summarizes the NAMT requirements and benefits by the defined participation levels.

Table 3-1 NAMT Levels, Requirements and Benefits

PARTICIPATION LEVEL	MINIMUM REQUIREMENTS	BENEFITS
Core Node (Long Term Commitment)	Contribute major facilities or resources to the NAMT. Provide full-time personnel for the management and/technical program. Contribute to Strategic Plan Sign NAMT terms of reference	Program governance through Executive Steering Panel membership. **<u>(All benefits below)</u>**

PARTICIPATION LEVEL	MINIMUM REQUIREMENTS	BENEFITS
Project Node	Provide unique DVM capability to NAMT (such as technical and management resources) Contribute to Strategic Plan Sign NAMT terms of reference Participate in at least one project	Access to and leveraging of NAMT resources Access to deliverables from NAMT projects as specified by the NAMT terms of reference. Development and validation risk reduction Project deliverables
Project Member	Sign NAMT terms of reference Participate in projects, either through Project or Core Nodes	Access to and leveraging of NAMT resources. Project deliverables
Open	None	Public Information

NOTE - The terms of reference is an individual agreement that must be developed for participation in the NAMT. It will include commitments of resources, staff and intellectual property rights.

3.2 Management Structure

NAMT will be structured to minimize the cost and maximize the benefit of collaborative development, evaluation, testing and deployment of distributed and virtual manufacturing systems. The program will operate under a joint industry-government management structure. This structure will distribute responsibility for the program and obtain the broadest possible industry representation.

The NAMT management structure is depicted in Figure 3-1. It is explained below in terms of the groups of individuals contributing to the program, their primary contributions and the recipients of those contributions.

The Executive Steering Panel will be composed of industry and government senior executives. The panel will set policy and program direction and approve the Strategic Plan for NAMT.

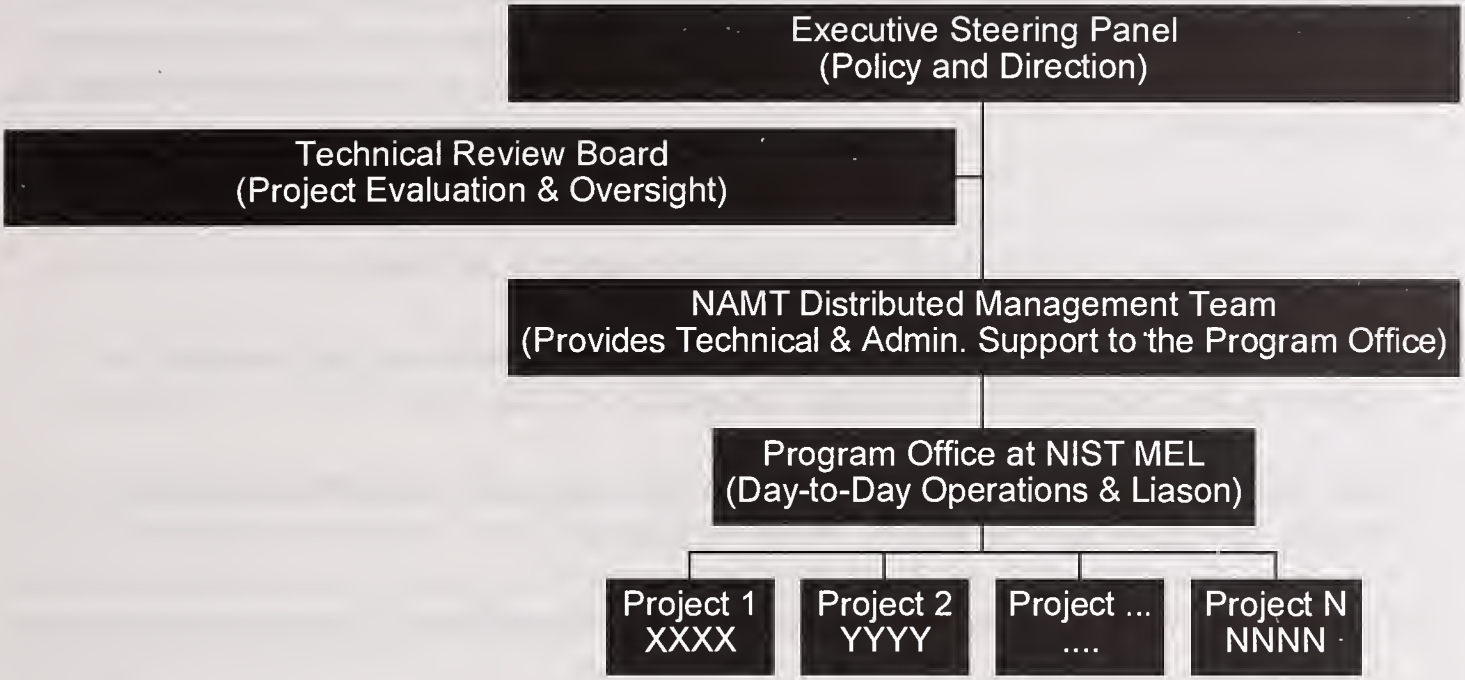

Figure 3-1 NAMT Management Structure.

A Technical Review Board is responsible for project screening and overall project oversight as described in Chapter 5.

A Distributed Management Team from each of the core nodes will interface with the NAMT Program Office on a regular basis. This Distributed Management Team will consist of personnel who reside at the individual core and/or project node locations. This team will be responsible for the development of the NAMT Strategic Plan.

The NAMT Program Office is the central focal point for NAMT and will reside within the NIST Manufacturing Engineering Laboratory (MEL). The office is responsible for the daily operations of NAMT including project coordination, facilitation and other service functions.

Each project conducted as part of NAMT will have a project manager who will oversee project execution and be responsible for interfacing with the NAMT Program Office as required.

Additional details regarding the NAMT Management Structure can be found in this document's Appendix B.

3.3 NAMT Operations

Operational issues for NAMT have both unique and generic aspects. A set of value added services must be developed and business and contractual issues associated with collaborative efforts must be resolved. This section provides a brief description of these elements.

3.3.1 First Steps

Upon the initiation of the NAMT, the following actions will occur.

- The core nodes and their commitments will be finalized and the terms of reference for the NAMT will be developed.

- NIST MEL will name the NAMT Program Manager and the core nodes will identify the staff for the NAMT Program Office.

- The NAMT Program Office at the NIST MEL will officially commence operations.

- An initial set of NAMT services (described in the next section) will be made available through the NAMT Program Office.

- The NAMT Executive Steering Panel will be established and will meet to define initial NAMT policies and set the initial milestones for the program office.

- The Distributed Management Team and the Technical Review Board will be established

- A broad public announcement of the NAMT and a call to identify NAMT projects will be issued.

- A set of initial start-up projects (one or more) will be selected at the initiation of NAMT.

3.3.2 Services Provided

NAMT will operate at both a program level and at individual project levels. At the program level, the services offered through the NAMT Program Office will include the following.

- General technical and administrative assistance on an as-needed basis will be available to all active NAMT projects, as will project planning support for potential projects.

- DVM related workshops and conferences will be initiated and facilitated.

- An information repository will be created and maintained that catalogs all DVM related project information. This DVM information repository will be accessible through existing electronic communication networks such as Internet and will be publicly accessible.

- Based on an analysis of project information, a roadmap for DVM technology will be developed. The critical areas where additional work is needed will be identified in this roadmap.

- A capabilities database will then be produced that identifies technical and programmatic voids that can be addressed by NAMT.

3.3.3 Intellectual Property, Business and Contractual Issues
NAMT projects will involve multiple organizations working together in the pursuit of technical objectives. As such, there will be nontechnical contractual, business issues, proprietary information and intellectual property rights issues that must be addressed.

NAMT does not have a unique solution to this problem. There are many types of model legal agreements (CRADA's, Intelligent Manufacturing Systems Terms of Reference, Interagency Agreements, Memoranda of Understanding) that have been developed to overcome such barriers. Several organizations are presently developing such agreements. *The aim of this program is to have a variety of industrial organizations and the government work together for a mutual benefit*. If existing model agreements do not satisfy the NAMT partners, then these legal issues will be handled on a case by case basis.

Chapter 4. DVM, Nodes and Networks in NAMT

The terms distributed manufacturing and virtual manufacturing as they apply to the NAMT and the communications structure for the NAMT are described in this chapter.

4.1 Distributed and Virtual Manufacturing

4.1.1 Distributed Manufacturing

Distributed manufacturing is the set of activities performed at geographically separated sites to design, produce and support a product or set of products.

A large number of companies are using distributed manufacturing within the U.S. or globally where each facility performs one or more manufacturing process functions. Typically, this is done with proprietary or single vendor solutions to overcome the interoperability issues. This means that a supplier or a risk partner of a particular product manufacturer will have to modify their systems in order to engage in a business relationship with another manufacturer.

In context of the NAMT, distributed manufacturing implies there is an open set of standards and interfaces that support the interoperability of manufacturing systems. The use of these standards and interfaces will allow partners and suppliers to interoperate with a variety of manufacturers. The NAMT network must be designed such that participating nodes can easily plug their systems into the network and access any *required* information.

4.1.2 Virtual Manufacturing

Virtual manufacturing is defined as the application of computer simulation and modeling to represent manufacturing processes and products. Within the context of the NAMT, simulations and models will be used to plan, perform, monitor, adjust and improve individual manufacturing tasks. The systems that are modeled and simulated consist of a wide range of items such as materials, products, machine tools, robots, sensors, controllers and production lines. The simulations and models must be verified with respect to actual manufacturing systems that have physical behaviors and interactions, such as motion, transfer and transformation.

The NAMT will have an array of technical projects (see chapter 5) that focus on DVM requirements to meet the goals of the program. One of the NAMT capabilities for validation will be rapid prototyping or fast fabrication. These techniques will provide the physical realization of a product to validate the virtual manufacturing description of a process or product.

4.2 The Structure of NAMT

NAMT will consist of a network of nodes that are geographically distributed. Figure 4-1 shows the communications structure of the NAMT. Communications will occur at three levels: the individual project node level, the project network communications systems level and the NAMT program level (NAMTLink). Each of these levels will be described. The ability of nodes to accurately communicate, exchange data, control machines and interoperate is a major concern of NAMT.

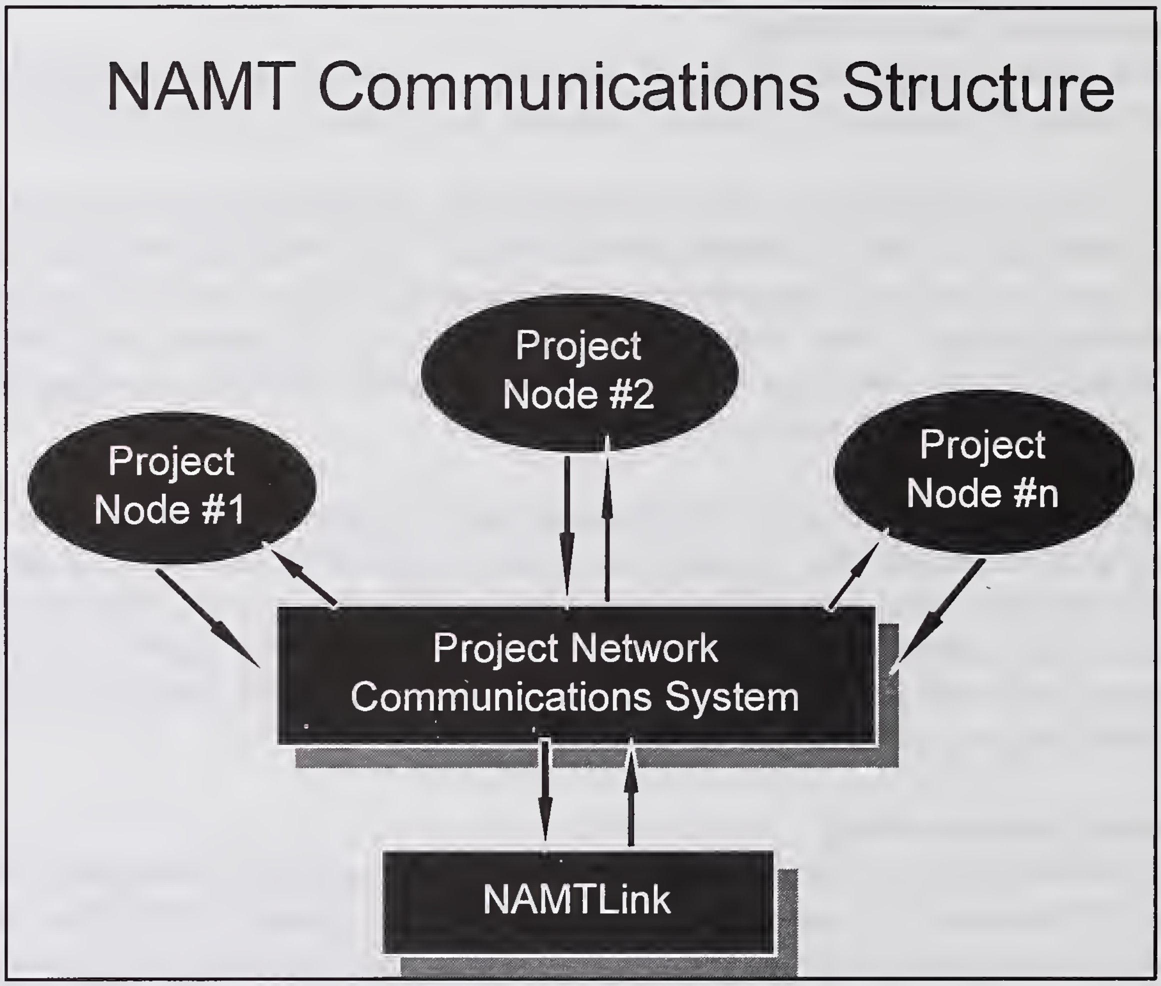

Figure 4-1 NAMT Communications Structure.

4.2.1 NAMT Nodes

Individual nodes will contain some or all of the following resources: simulation tools, design tools, specialized manufacturing equipment and staff to support the specific aspects of the manufacturing process and production.

A NAMT node shall be defined as a system or set of systems that exists at a specific physical location and is operational such that it functions to allow the exchange of information with other systems at other physical locations participating in NAMT. The capabilities of a node will typically include any of a number of manufacturing equipment types. However, for network communication purposes, the node will be considered as the computer and/or telecommunications systems that are physically linked into the NAMT communications system. It is important to note that more than one node may exist at one physical facility location and also that more than one system may constitute the capabilities of one node. **The ability of nodes to accurately communicate with and among one another in support of DVM objectives within integrated enterprises is a primary concern of NAMT.**

4.3 Network Standards and Technologies

The networked systems that comprise the NAMT are so dependent upon standards for information content, display and exchange, that it may be said that there is no DVM enabling infrastructure without the standards. NAMT network communication system concepts will employ these information exchange standards, both mature as well as those being developed. **The utilization of standardized technologies for electronic network communications and their integration into DVM enterprises is a major focus of the NAMT program.**

There are a significant number of private sector and government projects now focussed on hardware and software issues. The following examples are not comprehensive, but indicate the types of issues where NAMT will use the best available results and help with validation of the solutions that will be addressed in NAMT. Hardware items include interfaces to promote plug-and-play capabilities among manufacturing, computing and communication systems as well as physical protocols and communication lines for transferring information. Technologies also refer to issues associated with software compatibility, including software used for machine programming, graphics display data manipulation, information and data exchange and data retention. A major area of national concern is privacy and communications security. The NAMT network will use the best commercial security solutions available.

4.4 Program Network Communications System

NAMT will have a network communications system at the program level that will exist to serve several functions as depicted in Figure 4.2. It will primarily serve as the main communication vehicle for all participants in NAMT. It will physically exist, at least initially, as a link into the Internet and will be known as the **NAMTLink.**

NAMTLink's existence will be analogous to a NAMT home page on the World Wide Web (WWW). NAMTLink will be accessible from the WWW, but it will not be restricted to the WWW to accommodate those entities that cannot access WWW (e.g., SME participants). NAMTLink will not have the vast array of capabilities that individual project networks will have.

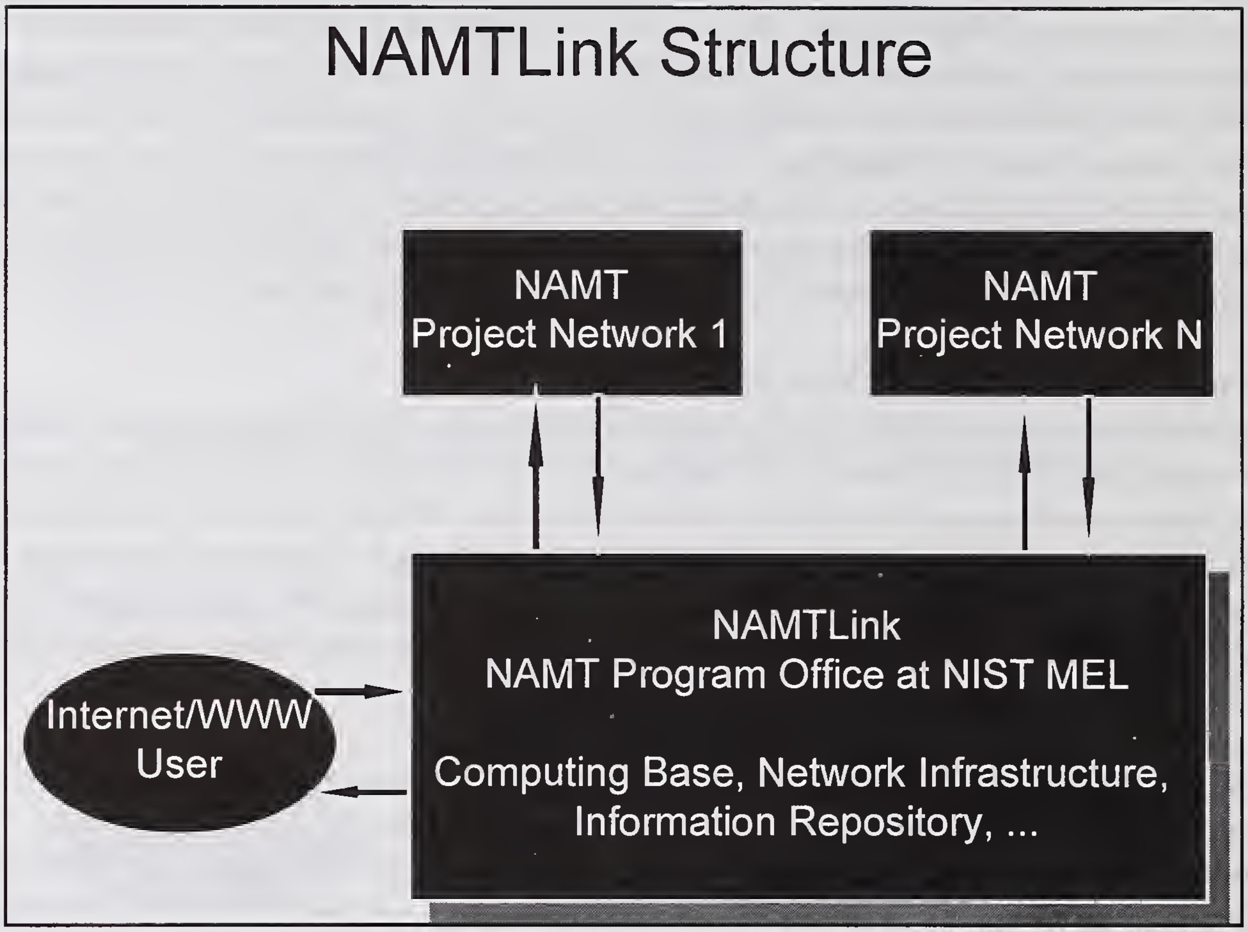

Figure 4-2 NAMTLink functions.

NAMTLink will act as an information repository that serves as a conduit of program information with unrestricted access among NAMT participants. There will be access capabilities for non-NAMT participants as a means of transmitting public program information. Examples of the types of information exchanged on NAMTLink may include NAMT Program announcements, lists of active NAMT participants and projects (a NAMT points-of-contact directory) and an active dialogue system by which participants can share generic problem information or success stories about projects.

NAMTLink will initially be neither a development, nor standardization mechanism. Its initial purpose will be the public dissemination of program information.

4.4.1 NAMTLink and the NAMT Program Office

NIST will serve as the system administrator for the NAMTLink and will conduct this function in conjunction with the NAMT Program Office in the NIST MEL. At least one state-of-the-art computer server will be part of this network communication system to operate NAMTLink. NIST has several computer servers already linked into the Internet and uses the WWW, ftp and gopher to connect to the global community.

The technical specifications, such as the standard interfaces, data exchange, communication protocols, system control scheme, servers and routers used for NAMTLink will be developed as required. NAMTLink specifications will be designed to allow open access and use accepted standards wherever possible.

Initially, the NAMTLink will have functionality that includes, at a minimum, the electronic transfer of alpha-numeric text files, graphics files and video images. The specifics of these transfers will be defined and refined as the program progresses and will initially interface with presently available network communication systems.

4.5 Project Network Communications Systems

In addition to NAMTLink, NAMT will consist of individual project network communication systems. These project networks will provide the means of electronic communications for individual NAMT projects. Project network communication systems will be technically driven by the project participants and NAMT will serve to assist in network interoperability and standardization issues.

Project network systems will leverage existing networks as appropriate. It is outside of the focus of NAMT and its projects to replace the Internet or other currently available electronic networks. It is, however, within the focus of NAMT to improve interoperability within and among networks in support of DVM enterprise objectives.

NAMT project network communications systems will possess the capabilities for the accurate exchange of a multitude of different types of information in support of the DVM enterprises operating in each of the projects. Access to these systems will be restricted in such a way that is mutually agreeable to the project participants and the specific restrictions will be developed in conjunction with each individual project. The issues regarding information exchange will be addressed by coupling with the appropriate standards and standards activities.

These project network communications systems will be capable of communicating with the NAMTLink as negotiated by the project participants. The purpose of placing restrictions on access to these systems is to protect the participants of individual projects in terms of intellectual property, maintain the integrity of the project's technical objectives and address potential sensitivities associated with competitors working in a common environment. These restrictions will be negotiated among the project participants and the NAMT Program Office, prior to the initiation of projects.

4.6 Project Network Communications Systems Functionality

There are two primary issues, information exchange and connectivity, that define a node's communication functionality.

4.6.1 Information Exchange Functionality

Information exchange functionality issues include a node's ability to accept and transmit data in standard formats, such as STEP. It is not practical to mandate that a node have a certain level of STEP functionality. However, it must be required that a node be able to demonstrate a minimum capability to transmit and receive product and process data specifically associated with the technical objectives of the its projects.

4.6.2 Connectivity Functionality

Connectivity functionality includes the issues that must be addressed which are related to the ability of one or more nodes to physically communicate with other nodes. Included here are standard interfaces for different systems, communication equipment and manufacturing equipment; communication protocols among systems; network control schemes and servers and routers. Connectivity functionality will be greatly facilitated through standardization; however, as with other issues, it is out of the scope of this document to specify which hardware or software must be employed for a particular purpose.

The minimum connectivity functionality must be established by project participants based upon the objectives of the project as matched with the various manufacturing and communications systems employed within the project.

System modularity is an important element that must be considered when defining a node's connectivity functionality, as well as its information exchange functionality. This is important to facilitate the capability of different systems and machines to be efficiently added to, removed from and interchanged with the networks as needed. NAMT Project Networks are required to have interface capabilities that will address DVM technologies used by the specific project.

4.7 Integrating NAMTLink and NAMT Project Communication Systems

NAMT will integrate NAMTLink and individual project network communication systems. NAMTLink and the individual project network communications systems will possess capabilities to allow information exchange on a restricted basis, as described earlier. The maturing of various standards through scenario-based demonstrations will be used to integrate individual communications systems with one another. This will be done to improve the accuracy of information exchange as part of DVM solutions.

Chapter 5. Projects

The NAMT will be built around an array of technical projects designed to pursue the program mission. This chapter describes and defines NAMT projects and the project screening process. As a reference for participants, there are synopses of sample projects included in Section 5.3.

5.1 NAMT Projects - Described and Defined

To be a NAMT project, the effort must support the basic program mission. A set of criteria and guidelines for NAMT projects were developed to determine initial suitability of proposed efforts. The details and process used to develop criteria and guidelines are given in Appendix C. NAMT projects must:

- **support the NAMT mission,**
- **identify the industrial impact in terms of defined benefits,**
- **provide a complete, specific and feasible technical plan,**
- **identify industrial participation and commitment**, and
- **define the relationship of the project to the NAMT organization.**

5.1.1 Support the NAMT Mission

A project must show that it aligns with the mission of the NAMT. Projects should: use multiple, geographically distributed facilities, or nodes, to support project objectives; show an indication of industrial interest and support; and clearly define methods to test and verify results. Ideally, the anticipated project facilities should possess specialized or unique combinations of capabilities that add value to or advance DVM.

5.1.2 Identify the Industrial Impact in Terms of Defined Benefits

NAMT projects must clearly demonstrate and define their industrial impact. Quantitative measures of the benefits of the targeted DVM improvements are needed. The project plan should map relationships among OEMs, suppliers, manufacturers and vendors. Projects should identify the benefits to SMEs and their suppliers. Where practical, projects should measure the impact on cost related to the linkages of project participants per the industry-defined project scenario. This could be direct or indirect as with projects which measure time-to-market change identified by manufacturing cycle-time/lead-time reduction, or improved efficiency.

5.1.3 Provide a Complete, Specific and Feasible Technical Plan

The technical plan is a description of what the project is going to accomplish. The plan should define an enterprise that uses DVM concepts, define the nodes and define all relevant systems. The plan must identify funding, staff and facilities. Targeted interoperability issues should be addressed. The plan should identify leveraging elements for the projects, such as related efforts underway. The project must define standards development and testing and should include a goal and methods for achieving that goal. Finally, the project plan should address the business impacts and implementation risks of adopting the targeted DVM technology.

5.1.4 Identify Industrial Participation and Commitment

The plan should define an enterprise that contains the elements of a supply chain, including a combination of suppliers, manufacturers, vendors and technology providers. The plan must outline node-by-node resource availability. The plan should clearly outline available funding and leveraging opportunities.

5.1.5 Define the Relationship of the Project to the NAMT Organization

Projects have a relationship to the NAMT organization. Project interactions with the NAMT Program Office and the other participants should be explained and information on what aspects of the core node facilities would be used.

5.2 Project Screening and Refinement

The process of submitting projects to the NAMT Program Office is not a proposal evaluation and selection exercise. However, since NAMT resources are finite and will be available for project use, an alignment process is necessary to ensure that NAMT resources are allocated to appropriate projects. NAMT is not a source of direct funding for projects, but it does provide resources for projects as outlined in Chapters 3 and 6. The program office also assists projects in the identification of funding sources.

Project screening will be a joint effort between submitting organizations, the Technical Review Board and the NAMT office. Any organization with a project idea for the NAMT should submit it in summary form to the NAMT Program Office at NIST. The NAMT Program Office will work with the submitting organization to refine the project as required. This is a process in which the NAMT Program Office will work with a submitting organization to ensure that they satisfy the NAMT project criteria.

5.3 Example Projects

The five project criteria presented in section 5.1 define what NAMT projects should be. When organizations submit project summaries to the NAMT Program Office, the project summaries shall be reviewed according to these criteria to determine how well they are aligned with the concepts of NAMT.

Fifteen project summaries were received at NIST in January 1995 at the initiation of this plan. No criteria or project format had been established. A screening process was applied to the initial submissions. The specific details of this initial screening process are presented in Appendix C. To summarize this process, a team of NIST evaluators independently classified a project into one of two main project types, then applied a weight scale to the criteria based upon the project classification. They then assigned a value to the project for each criterion. Projects are classified as either DVM Enterprise Infrastructure Projects, or DVM Enterprise Integration and Operation Projects. These project classifications are explained in Appendix D.

Based upon this initial evaluation, it was determined that only two of the project summaries ranked high with respect to the criteria. These projects can be used as benchmarks for the type of projects that fit within the scope of NAMT. There are two cautions a reader should note: these projects were only evaluated by NIST staff and no set of criteria had been developed prior to submission of these summaries. A call for project summaries will be made at the startup of the NAMT program.

5.3.1 Agile Manufacture of Castings

The summary "Agile Manufacturing Development of Castings," a DVM Enterprise Integration and Operation project, is given in Appendix D. It is an example of a project that fits well with the identified NAMT criteria.

> The project involves significant and specific industrial participation that includes a prime contractor, suppliers and engineering analysis providers.
>
> The project establishes a DVM enterprise consisting of several geographically distributed nodes, each conducting unique functions in the development of a new product which is cast.
>
> The project pursues DVM-related technologies such as information sharing, rapid fabrication, simulation and modeling.

The project summary does a concise job of explaining why this project satisfies the basic NAMT mission, explaining what the potential industrial impacts of the project are and providing the details of a brief technical plan for a 30-month project. Specific, industrial participation is identified. The summary explains how the project will relate to the NAMT Organization.

5.3.2 Rapid Manufacture of Complex Geometry Parts

The project, "Rapid Manufacture of Complex Geometry Parts in an Advanced DVM Environment," described in Appendix D is another example of a DVM Enterprise Integration and Operation project that fits well with the identified NAMT criteria. This project was evaluated highly in its initial review for similar reasons to those of the Agile Castings project. The project was rated slightly lower in its definition of industrial participation, since industry commitments were not firm at the time of the project summary's preparation.

The strengths of this project include the following.

The project includes multiple, geographically distributed facilities acting collaboratively to improve the production of parts that consist of complex geometric features.

The project integrates distributed and virtual technologies with advanced machining processes and incorporates them into a DVM environment.

The project identifies specific node capabilities, including several unique facilities which will be leveraged and which reside at one of the NAMT core node organizations.

In Appendix C a list of 13 other projects reviewed in the initial screening process is provided.

5.4 NAMT Initial Core Capabilities

At program initiation, NAMT will have a set of core capabilities and resources available for projects. These core capabilities refer to the special resources that are available for NAMT projects to leverage. The facilities and technical expertise available at this time are stated in Section 3.1.1. As NAMT evolves and attracts participants the core capabilities will increase.

Capabilities available for use as part of NAMT at the core nodes represent national resources that are highly capitalized and in many cases unique, as highlighted in Chapter 3. The leveraging potentials for projects participating in NAMT based on these capabilities alone are significant. Further details on these valuable capabilities, useful in project planning, can be found by contacting the NAMT Program Office at NIST.

Chapter 6. Relationship To Existing Programs and Funding

A variety of organizations within the United States are *independently* working on projects that lead to DVM capabilities. Coordination and leveraging resources are essential to achieve the 21st century environment. This Chapter discusses the relationship of NAMT to existing organizations and programs and the resource and funding options for partnering in the NAMT program.

6.1 Initial Relationships

Building synergistic links to existing organizations and projects has been a priority for NAMT planning from the beginning. Representatives of a number of established programs and sponsoring organizations (see Appendix A) have been active in all aspects of the planning process for NAMT. They include: the Advanced Research Project Agency (ARPA), Agility Forum, Automotive Industry Action Group (AIAG), Electronic Commerce Resource Centers (ECRC), Joint Director of Laboratories Manufacturing Science and Technology Program (JDL MS&T), Manufacturing Extension Partnerships (MEP), National Center for Manufacturing Sciences (NCMS) and Technologies Enabling Agile Manufacturing (TEAM) Program. This involvement began the process of ensuring that the NAMT will be integrated with and provide complementary capabilities to important DVM related programs initiated by these organizations.

While not comprehensive, the following provides some of the reasoning behind linkage of NAMT planning to the above mentioned programs and organizations:

- ARPA is sponsoring a wide variety of programs which provide aspects of DVM capabilities. Examples include a spectrum of Agile Manufacturing technology development, business practice and pilot projects; the MADE program and the Simulation Based Design effort. Further, ARPA has stated an interest in ensuring that their DVM related programs integrate with the NAMT.

- Two representatives of the Agility Forum were directly involved in the NAMT planning process. The Agility Forum is developing a broad industry consensus of user needs and information system voids that would be input for the development of solutions. They offer a strong potential source of requirements refinement and lessons learned.

- The AIAG is a strong supporter of supplier integration for the automotive industry. They have a vested interest in implementing solutions which rely on interoperability and have sponsored a variety of pilot efforts related to the electronic interchange of business and technical information. They have expressed interest in collaborating on a NAMT project.

- The mission of the ECRC is to create a world class supplier network by linking U. S. industry to the National Information Infrastructure and thus improve the way DoD and industry do business. Their charter is to work with government organizations and small to medium size enterprises to enhance manufacturing productivity, reduce time to market and improve quality at a reduced cost. Therefore, the ECRC's can help NAMT by identifying opportunities to apply information technology. In addition they can provide awareness of electronic commerce standards and enabling technologies, provide education and training, provide consultation and technical support and demonstrate uses and applications.

- The JDL MS&T program has been a consistent sponsor of DVM related efforts. They are currently pursuing programs in the Manufacturing and Engineering Systems and Advanced Industry Practices areas which are directly aligned with NAMT goals. These include such programs as product data activities, lean practice implementations and multiple defense related pilots. They have stated an interest in future cooperation.

- The MEP program was represented in the planning process with two members being involved in the plan development. MEP will be involved in the NAMT in two specific ways. They will identify and fund small manufacturers to become involved in projects. Secondly, they will work with the NAMT in developing processes which are appropriate for the smaller manufacturer. The Manufacturing Technology Centers (MTC's) will play a very important role of bringing the voice of the smaller manufacturer to the program and deploying the appropriate technologies which are developed to them.

- NCMS was directly involved in the NAMT planning process. They sponsor projects and provide requirements coordination. Consortia like NCMS could bring collaboration of their members to ensure proper focus and to utilize NAMT resources. They could also become a node on the testbed to provide their unique services. The design requirements which consortia are creating in specific domains would act as input for creating NAMT projects to meet real industry needs.

- Several TEAM members were involved in the NAMT planning process. TEAM has been defining the global industrial needs and how to fit them into the product and process design and manufacturing processes. TEAM has also taken an inventory of tools which can be integrated based on the set of industry-government participants. NAMT could assist in providing the testbed and the validation methodology for the interoperability and testing from a standards point of view. This testing could include the metrics of robustness and ability to scale.

6.2 Potential Future Relationships

The organizations mentioned above are active in various facets of advanced manufacturing technology development. NAMT's mission relative to these and other participants in the NAMT program will be to focus on the interoperability and validation issues which need to be addressed to achieve DVM. This focus differentiates NAMT from other initiatives and sets the context for close cooperation with other programs. NAMT will rely on the many participants "to do what they do best" and link to the NAMT.

The initial participants in the planning process do not represent a complete set of the organizations to leverage projects and coordinate with on a national scale. Toward building future relationships the first activity that will be undertaken when the NAMT program starts is the development of a baseline that identifies the existing programs which perform DVM related activities or functions. A road map can then be developed to ensure that there is a minimization of duplication.

6.3 Resources and Funding Options for the NAMT Program

The NAMT effort, projected to start in the second quarter of 1995, is a 5-year $13 - 25 M per year joint industry-government program for implementation of a multi-site, multi-organization "distributed and virtual manufacturing testbed".

Resources to establish and maintain this program are facilities, staff, equipment and funds. Some of the core resources have been defined in Section 3.1.1.

The NIST Manufacturing Engineering Laboratory will commit $3 - 5 M per year for the establishment of a NAMT node, projects and program office. There are associated NIST programmatic efforts such as the High Performance Computing and Communications (HPCC) program, Systems Integration for Manufacturing (SIMA) program and Manufacturing Extension Partnership Program (MEP) expected to contribute $5 - 10 M per year. The other initial core nodes, Oak Ridge and Sandia National Laboratories, will provide facilities and staff for this effort.

NAMT resources are facilities and staff with technical expertise that provide an infrastructure to initiate projects focussed on the solutions to the roadblocks to DVM. As such, it is not a source of direct funding. The projects are developed by the participants engaged in the NAMT. Options for funding of projects are through traditional government agency programs and private sector channels such as consortia, associations and self-funding. Many of the organizations listed in Section 6.1 have indicated interest in providing resources for NAMT projects and related efforts. All projects that participate in the NAMT are required to identify their resources that contribute to their project deliverables.

It is the aim of the NAMT to leverage resources and coordinate with all identified DVM efforts to the extent practical.

Chapter 7. Technology Transfer

Technology transfer is critical for U.S. industry to remain competitive and develop the edge for growth. NAMT will not establish a technology transfer organization. Rather it will establish links to Manufacturing Technology Centers, Electronic Commerce Resource Centers, technology suppliers and other specialists to promote training and educational activities. NAMT, through existing organizations and mechanisms, such as guest worker agreements and CRADAs, will facilitate the transfer of DVM technologies, help generate awareness, develop receptiveness and promote faster use by industry.

7.1 Principles & Statements of Intent for Technology Transfer in NAMT

NAMT project participants must provide reasonable information and documentation to the program office.

- **Where appropriate NAMT activities will contribute to the transfer of the tools, lessons learned and technology**

The program office will be the focal point for information, conferences, workshops and the conduit for awareness activities. NAMT technology transfer requirements will be formulated such that it does not add excessive overhead or burdens to the individual projects.

- **Facilitate transfer of DVM technology using distributed access to shared resources.**

By facilitating the integration of national resources, NAMT will reduce duplicate technical developments by providing access to corporate, government and academic resources. NAMT will act through either local distributed sites, such as MTC's, or through larger, centralized nodes in order to disseminate information and/or data. Commercial technologies will be recommended and used when they satisfy requirements. Endeavors will be made to make people aware of existing technologies and appropriate applications.

- **Facilitate the provision of hands-on use and education and training to accelerate technology implementation**

The most effective way to transfer technology is active participation in projects. Guest worker agreements, personnel exchanges and summer employment for university faculty and students will be promoted. Education and training programs will be developed and provided by educational institutions, commercial firms, MTC's, trade associations and others on a localized basis. The NAMT program office repository and on-line electronic library will provide information about the availability of materials, programs, conferences and commercial opportunities for training.

- **Provide a Window on the Technology for industry leaders, senior government officials and Congress**

The NAMT will promote visits to nodes, video-links, demonstrations and conferences on a planned basis for the target groups. NAMT will use the approach based on the experience of the NIST Automated Manufacturing Research Facility (AMRF). The AMRF attracted thousands of industry personnel, industry leaders, and senior government personnel who visited the facility. Staff from many institutions came to work on research and development projects to advance the state-of-the-art of manufacturing and transfer technology to individual companies.

- **Ensure that intellectual property rights are respected.**

Intellectual property rights (IPR) provisions are intended to ensure that: 1) Contributions and benefits by participants, from cooperation in NAMT projects, are protected, equitable and balanced; 2) The proper balance is struck between the need for flexibility in partners' negotiations and the need for uniformity of procedures among projects and among participants; and 3) The results of the research will be shared by the partners through a process that protects and equitably allocates any intellectual property rights created or furnished during the co-operation.

7.2 The Specifics of Technology Transfer under NAMT

As part of project initiation, NAMT project participants must provide the NAMT program office with materials describing the who, what, when, where, why and how of a project.

- **Providing the transfer of DVM technology**

Progress reports will be submitted on an agreed to basis to the program office. Within IPR and resource limitations, visits to node sites will be arranged through the program office. Guest worker personnel exchanges will be actively encouraged. The issue of availability of software and hardware documentation and tools will depend on the project and IPR restrictions for that project. Vendors will be encouraged to commercialize the products developed so that it will be available to the marketplace.

- **Facilitating the transfer of DVM technology using distributed access to shared resources.**

Within the NAMT Program Office, a World Wide Web (WWW) site will be established that provides repository information and links to other related DVM information. Any individual or company can access basic information through networks such as the Internet.

- **Ensuring that intellectual property rights are respected**

In general, the companies or individuals that develop or contribute previously developed software, hardware or other items deemed as intellectual property shall have the right to retain the material. Section 3.3.3 provides a discussion of intellectual property, business and contractual issues.

- **Facilitating the provision of education and training to accelerate technology implementation**

The nodes in general will help DVM users understand new processes and facilitate training opportunities with "hands on" access to demonstrations and learning materials. This will support industry in meeting evolving business needs. It will acquaint individuals and organizations with the information necessary to execute their tasks as they relate to technological advances.

Nodes may set up forums for local manufacturers to get together and informally discuss generic technologies, what works and what doesn't. Wherever possible the program office, nodes or project managers will provide a "neutral environment" such that private sector firms, without exposure to the competition or embarrassment, can get up to speed on the technologies or work with an expert who is not selling a specific product or service.

Chapter 8. Critical Success Factors, Metrics and NAMT Program Phases

The preceding sections describe the conceptual design and development of a national distributed testbed resource. We recognize that the **ultimate value and success of the endeavor will be measured by industry participation.** This section looks first at the success factors and participation metrics in general terms. It closes with an example of how we see that the emerging NAMT will be measured.

8.1 Critical Success Factors

From an analysis of the foregoing sections, there are three factors which appear to be most critical for NAMT success:

- commitment;
- effective competency-based collaboration; and
- visible benefits achieved through managed processes.

Commitment is made at two levels: a strategic level and a tactical level. At the strategic level, NAMT requires the commitment of sustaining partners who provide dedicated resources over the long, multiple-project, term. These are the providers of core or sustaining nodes and represent the major architects of the NAMT program. At the tactical level, there is an absolute need for commitment on the part of industrial organizations to design and to participate in the NAMT projects. Underlying both levels is the need for commitment of the participants to the principles of teamwork-based excellence and continuous process improvement.

NAMT goals will be met through collaborative efforts between and among industrial organizations, academia and governmental agencies. Such collaboration must be both effective and competency-based. Part of the competency-based activities are obvious in that nodes are to be built around special capabilities, such as equipment, systems or personnel.

The size and importance of the DVM problem amplifies the need for cooperation. NAMT is not intended to develop the total solution to domain issues. Rather, it seeks to build cooperative solutions which are of mutual benefit to multiple parties. As such, it must be viewed by the many activities already seeking improvement in DVM capabilities as fulfilling needs associated with testbed activities.

Building a collaborative spirit has a significant impact on NAMT operations and startup requirements. Organizationally, NAMT must not duplicate. It must not elicit views of "we already do that," but rather of "together, we can do better." From the industry collaboration perspective, NAMT must impart the view that reducing risks, sharing results and insuring project collaboration will pay off. The value of critical mass directed at coordinated problems must be at the forefront.

In the aggregate, the critical success factor for NAMT is founded on visible results and specific benefits. NAMT benefits imply those which will be gained from individual projects and the NAMT-integrated projects. Individual projects must meet their own cost, quality or schedule related goals. At the same time, the coordinated stream of projects in support of one another must make more progress toward the DVM vision than they could realize individually. The benefits of mutual support against the DVM application domain will demonstrate that NAMT is a value added program. Examples of measuring value added include a variety of global beneficial results such as:

- lowering the cost of collaboration through providing an infrastructure and fresh links for technology transfer;
- working through national bodies to contribute to the development of distributed and virtual manufacturing related standards;
- coordinating and leveraging the DVM projects to assure the availability of sustained critical mass resources; and
- bringing together technical experts and making this expertise broadly available.

The benefits will be achieved through a set of measured processes which:

- balances project needs with national needs;
- provides priorities which ensure that sponsored efforts are focused on important, rather than urgent tasks;
- allows for periodic evaluation and review by user-driven external and peer groups;
- provides efficient, reliable and cost effective operations to provide validated solutions to program objectives; and
- provides direct access to industrial and governmental research, technology, systems and processes.

8.2 Metrics

As NAMT evolves, four types of metrics (activity, progress, output and significance) will be applied to the program:

- **Activity metrics** will measure the effort expended on directed activity.

- **Progress metrics** will measure achievement of scheduled milestones.

- **Output metrics** will measure productivity of useful results such as technology transfer to supplier chains; or, for individual projects this will translate to cost reduction, to increased quality and to schedule compression.

- **Significance metrics** are measures of the beneficial impact to an industrial sector or sectors. For the NAMT as a whole, the development of meaningful metrics associated with its overall impact will be both important and difficult. Methods to evaluate the value of cooperation and innovative change must be pursued.

Each of the foregoing metrics types plays a role in the various NAMT phases. At the project level, there will be relatively easy measures available. The critical issue will be in determining the significance metrics for NAMT as a national testbed.

8.3 NAMT Measures

Prudent management demands that programs be measured as well as executed. The NAMT management team is committed to the process of maintaining a measurable program definition during the maturation of the program.

Realizing that NAMT will exist as a dynamic program that will change and evolve during its maturation, it is necessary to define the measures that will be applied to NAMT in terms of a context for the evolution of the program. This context and measures are provided in the following section.

8.4 Program Evolution

NAMT exists now in terms of a conceptual design and has a set of goals that are targeted against a vision and a mission. NAMT will not emerge full-blown onto the technology development and implementation stage. Rather, it will be built in measured steps by an industry-academia-government coalition. At the time of the production of this document, the NAMT evolution is viewed in terms of four phases and four gates as shown in Figure 8 - 1.

Phase **Time Frame**

Foundation (6 mo)

Ramp-up (12 mo)

Sustainment (44 mo)

Sunset Review (at 54 mo)

Gate# 0 1 2 3

Figure 8.3 NAMT evolution.

Table 8 - 1 below provides the specific measures and activities during the various phases of NAMT

Table 8 - 1 Application of Gate Measures at NAMT Phases

Gate #1 Ramp-Up Phase	Gate #2 Sustainment Phase	Gate #3 Sunset Review Phase
- A phase plan for ramp-up phase. - Defined operational procedures which include special attention to NAMT communications and technology transfer. - A set of initial projects which involves both core and project nodes. - A defined set of cooperation targets in terms of both organizations and specific projects. - An initial NAMT set of services. - Output results expectations on a per-project basis. - Filled management and oversight boards.	- An industry and government validated plan for the sustainment phase. - Refined operational procedures. - Version 1 of a National DVM roadmap. - Activity marks and progress against the Ramp-up plan. - Evidence of collaboration & cooperation across active projects - A new NAMT project set developed through the selection process. - Proof of effective use of existing outlets for tech transfer and SME assistance. - Double the number of nodes. - Interim results of start up projects show promise.	- Decision on NAMT continuation beyond 5 years. - Refined NAMT operational procedures which provide for sustained flow of activities. - Version 2 of the annual DVM roadmap. - Activity marks and progress against the Sustainment plan. - Some of the initial projects successfully completed. - A completed "impact" report which provides for decisions about further sustainment actions. - Measured strategic progress against the NAMT vision. - Number of active projects built on core competency. - A NAMT services suite that is operational with defined activity measures.

8.4.1 Foundation Phase

The **foundation** phase takes place during the first six months of startup. This phase consists of the actions necessary to progress from this conceptual document (which provides a basis for participation decisions) to a strong foundation which provides a solid basis for future success. This foundation will be built on a set of initial targets, on the detailed business and management processes and on the committed resources necessary to execute the NAMT program. During this phase, the initial set of NAMT projects must be started.

Application of Gate 0

Measures can be provided in terms of snapshots. We know what we expect to see will change as we proceed through the foundation phase. At this time, the snapshots are defined in relation to four gates which separate the first three NAMT phases. The target start date is the second quarter of calendar year 1995 (April - June). Gate 0 is encountered at the end of the decision cycle following the publication of this plan.

Gate 0's name was chosen with care. It is, in reality, a go/no-go decision point. There is a need for core or sustaining nodes and partners to provide the initial NAMT capabilities and commitment.

Commitment is in two parts. 1) The partners must be committed to supporting the first 3 years of the program, <u>independently of the specific projects</u> which will be executed. 2) They must be committed to the principle that for DVM domain problems, with testbed aspects, they will support projects through the NAMT umbrella process. There is an absolute requirement for a kernel of core resources to sustain the integrating functions of NAMT.

Without such commitment, there should be no decision to proceed with NAMT, as the national aspects of the programs would be doomed to sub-critical struggle against ever larger targets.

Specific measures applied to gate 0 are:

- firm identification and commitment of core nodes;
- NAMT Program Office at NIST MEL;
- NAMT Program Manager named from the NIST MEL;
- an Executive Steering Panel committed to serving through the foundation phase in place;
- support resources to provide the initial set of NAMT services and execute the program in place at NAMT Program Office;
- a preliminary set of foundation phase objectives and deliverables in place against which to measure the program;

- a broad public announcement of the NAMT and a call to identify NAMT projects will be issued; and
- a set of initial start-up projects (one or more) will be selected at the initiation of NAMT

8.4.2 NAMT Program Phases
Table 8-1 defines the NAMT activities that must occur during the next phases.

During the **ramp-up** phase there is heavy emphasis on initiating projects, providing initial NAMT services, defining participants, getting commitments, developing procedures and filling the various panels and oversight committees.

During the **sustainment** phase several projects will be active and additional ones will be in the startup and planning stage. Progress against NAMT goals will be measured against the set of new projects defined and started by the commencement of this phase. The NAMT services will be refined.

The **sunset review** phase will occur in NAMT's fourth year of operation. Project progress and results and program impact will be analyzed and evaluated. The evaluation will be against specific goals.

8.4.3 Application of Gates 1- 3
The present view of gates 1- 3 share some common aspects and are shown in Table 8 - 1. The specific measures in this table are very likely to change over time. What is important is that both the projects and the processes will be measured using the metric types described in Section 8.2. Specific measures for the anticipated end states will be required at the beginning of each phase.

The application of measures at gate #1 will occur during the ramp-up phase of NAMT. The application of measures at gate #2 will occur during the sustainment phase of NAMT. The application of measures at gate #3 will occur during the sunset review phase of NAMT.

The sunset review phase is where the decision will be made whether NAMT will continue beyond its initial 5-year duration. Based upon this decision, transition activities will occur as appropriate.

Ideally there should be more phases beyond the three mentioned in this section if NAMT fills a valid need and provides value added. The decision to sustain NAMT beyond 5 years will be made by the Executive Steering Panel. This means that the participants in NAMT must show the program provides more value than a coherent collection of projects. Despite the difficulty of this task, it is required to measure the success of NAMT.

Glossary

Automated Manufacturing Research Facility (AMRF): Starting in the 1980's the Manufacturing Engineering Laboratory (MEL) of the National Institute of Standards and Technology (NIST) developed and managed a flagship program to work on research and development projects to advance the state-of-the-art of manufacturing and to transfer technology to individual companies.

Distributed Manufacturing: Distributed manufacturing is the set of activities performed at geographically separated sites to design, produce and support a product or set of products.

Distributed Virtual Manufacturing (DVM): refers to manufacturing processes which are distributed, virtual or both. Distributed means that different aspects of a process occur in different physical locations. Virtual means that some aspect of a process is modeled by a computer to facilitate faster, more accurate decisions regarding how the process should proceed.

DVM Enterprise Infrastructure Project: refers to one category of NAMT projects. See Chapter 5.

DVM Enterprise Integration and Operation Project: refers to one category of NAMT projects. See Chapter 5.

Electronic Commerce Resource Centers (ECRC): Selected supply centers in the nation participating in the Continuous Acquisition and Life-Cycle Support (CALS) program.

Intellectual Property Rights (IPR): are legally binding agreements protecting the rights to literary, artistic and scientific works; performances of performing artists; broadcasts; inventions in all fields of human endeavor; scientific discoveries; industrial designs; trademarks, service marks and commercial names and designation; protection against unfair competition; and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields.

Integrated Product Process Development (IPPD): refers to the standards program underway in government and industry to formalize the exchange of product design and development information.

Manufacturing Engineering Laboratory (MEL): refers to a NIST Operating Unit focussed on manufacturing.

Manufacturing Technology Center (MTC): refers to a regional center set up to assist SME's in the adoption of appropriate technology.

Metrics: refers to the critical success factors for measuring the NAMT program. Four types of metrics will be applied to the program: Activity, Progress, Output and Significance metrics. See Chapter 8.

National Advanced Manufacturing Testbed (NAMT): A program to develop a network of specialized nodes geographically distributed which focus on DVM technologies to support all phases of the design, manufacturing process and product life cycle.

Rapid Prototyping: Physical realization of a product by fast fabrication techniques.

Red Team: a team of representatives from industry, government and academia to review critically the NAMT Program Plan.

Small and Medium Enterprise (SME)

Standards for the Exchange of Product Model Data (STEP): refers to the ISO Standard 10303.

Supplier Chain: refers to the organization of two or more customer-supplier relationships all working together to design, develop, manufacture and service customers in a marketplace.

Virtual Enterprise: a consortium of organizations formed for the purpose of providing a product to the global customer. Note: this is synonymous with Virtual Corporation.

Virtual Manufacturing: Virtual manufacturing is defined as the application of computer simulation and modeling to represent manufacturing processes and products.

World Wide Web (WWW): The World Wide Web is the universe of network-accessible information. It is an initiative started at CERN, now with many participants. It has a body of software, and a set of protocols and conventions. WWW uses hypertext and multimedia techniques to make the web easy for anyone to roam, browse, and contribute to.

Table Of Contents

Appendix A

Contributors to the NAMT Planning Effort

Appendix A. Contributors to the NAMT Planning Effort

Manufacturing Engineering Laboratory Planning Team

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John Cassidy	UTC	Director Corporate Research
Mike Coffey	NMTA	President
Mel Cohen	AT&T	Vice President Research Effectiveness
John Decaire	NCMS	Acting President
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Appendix B

NAMT Structure and Program Management Details

Appendix B. NAMT Structure and Program Management Details

The NAMT program is a cooperative effort in which U.S. participants work together to solve problems related to the establishment of distributed and virtual manufacturing enterprises. The NAMT program operates under the management structure discussed in Chapter 3 that consists of:

- Executive Steering Panel
- Distributed Management Team
- Technical Review Board
- Project Teams

The following is a more detailed discussion of the responsibilities of these bodies.

Executive Steering Panel
The Executive Steering Panel approves the NAMT strategic plan. The strategic plan establishes goals and boundary conditions for the NAMT. The Strategic Plan is created by the Distributed Management Team and used by the Technical Review Board in creating, maintaining, and updating the Technical plan.

The Technical Plan will contain details of the Focus Areas within NAMT in which industry requirements for distributed and virtual manufacturing indicate the highest priority needs. The Technical Plan is created by the management team, and used by the NAMT Program participants as guidance in developing their individual project plans.

Project Members use the project plans to guide the execution of NAMT projects. The project results are used by the participants to commercialize and/or deploy at their option. A report of the project results and the original project plan is given to the program management team to be used in guiding future projects as allowed by intellectual property rights (IPR) agreements.

The structure and content of the IPRs will be derived from existing mechanisms employed at participating nodes (e.g., CRADA, Memorandum of Understanding). Protocols for agreeing on these, and other legal and business issues, will be a top priority for the Executive Steering Panel. Also in accordance with IPRs some results will be made available for use by nonparticipants.

The NAMT program staff will maintain program archives and facilitate technology transfer. Project participants are the heart of the NAMT program. They develop, demonstrate and advance virtual and distributed manufacturing technology.

The NAMT Executive Steering Panel provides program oversight and sets strategic direction. Members of the Executive Steering Panel will include representatives from U.S. industry, Federal agencies, and academia who are knowledgeable of the research, development, and deployment issues surrounding distributed and virtual manufacturing enterprises.

The panel will meet no less than twice per year and no more than quarterly. An equitable voice for all participants in the conduct of NAMT operations will be ensured through the appointment to the Executive Steering Panel of participant members from smaller companies. It is proposed that the panel will always be chaired by an industry representative.

Executive Steering Panel Responsibilities
The responsibilities of the NAMT Executive Steering Panel include the following list. (The Steering Panel may elect to delegate a portion of these responsibilities to the NAMT Manager.)

- Provide overall guidance to the Program Manager.
- Set strategic priorities for the NAMT program.
- Form task forces or subcommittees necessary to accomplish its work.
- Ensure representation of industry, academia, and federal laboratories.
- Ensure that projects are meeting strategic priorities.
- Provide funding to support the operation and functions of the Program Office as needed.

Distributed Management Team
The NAMT Distributed Management Team will be a **distributed** entity coordinated from the program office which will provide project oversight, coordination, as well as logistic, technical, and administrative support to the NAMT Program. The Distributed Management Team will consist of a NAMT program manager, industry liaison, government program liaison, and any support staff required to fulfill the management team responsibilities (e.g., Deputy Manager, system administrator, librarian, or secretary).

NAMT Program Manager
The NAMT Program Manager is responsible for execution of the program as approved by the Executive Steering Panel, preparing the Technical plan, chairing the Technical Review Board and establishing mechanisms to support the communication and sharing of NAMT results (e.g., a document repository, e-mail exploders, and a database of NAMT-related information. Portions of these responsibilities may be shared with either the NAMT Distributed Management Team or individual NAMT project teams.

NAMT Program Manager Responsibilities (Details)
The overarching responsibility of the NAMT Program Manager is to provide value added services to the NAMT project teams and their sponsors. The responsibilities of the NAMT Program Manager includes the following list. These responsibilities may be delegated to either the NAMT Distributed Management Team or individual NAMT project teams. These responsibilities are

- Prepares Technical plans and interim reports.
- Execution of the program as approved by the Executive Steering Panel.
- Chairs the Technical Review Board.
- Coordination of the individual projects.
- Allocated resources as necessary to support NAMT operations.
- Educates new program participants.
- Disseminates information during and upon conclusion of projects in accordance with intellectual property rights agreements.
- Provides logistics for meetings.
- Provides facilitation of meetings as needed.
- Assists with launching of new projects.
- Facilitates the formation of new projects and consortia.
- Hires or leverages support staff as needed.
- Coordinates the activities of the industry and government liaison
- Facilitate the acquisition of resources as needed by technical projects
- Establish e-mail exploders for program and individual projects.
- Establish common file server and document archival (maintains corporate memory).
- Establish WWW server with links to related programs.
- Establish repositories of freely distributable software.
- Maintain a database of resources, contacts, and administrative information as needed.

NAMT Industry Liaison
The NAMT Industry Liaison will provide a direct interface to industries and industrial associations and consortium by identifying industry programs relevant to distributed and virtual manufacturing and establishing information links with them. Acquisition of industry needs, identification of potential projects and resources and communication of NAMT capabilities will be emphasized.

NAMT Industry Liaison Responsibilities
Specific responsibilities of NAMT Industry Liaison are:

- Coordinate the creation of project teams
- Create information links to existing technical programs in industry
- Identify technical experts in industry for the NAMT projects to source.

- Identify potential sources of industry funding for projects.
- Identify industry resources for use by projects.

NAMT Government Liaison
The NAMT Government Liaison will provide a direct interface to government agencies and their programs relevant to distributed and virtual manufacturing by establishing information links with them. Acquisition of government needs, identification of potential projects and resources and communication of NAMT capabilities will be emphasized.

NAMT Government Liaison Responsibilities
This individual reports through the NAMT Program Manager.

- Coordinate the creation of project teams.
- Create information links to existing technical programs in government.
- Identify technical experts in government for the NAMT projects to source.
- Identify potential sources of government funding for projects.
- Identify government resources for use by projects.

NAMT Program Management Support Staff
Program support staff will be obtained from the resources contributed by NAMT participants as needed by the Program Manager. This staff may be technical or clerical and the staff responsibilities will be determined by the Program Manager.

Technical Review Board
The NAMT Technical Review Board works to ensure the technical integrity of the NAMT program. The Board need not have regular meetings to fulfill its responsibilities but it is recommended that the board members attend the periodic program reviews.

The Board will consist of individuals with recognized expertise in technical areas related to distributed or virtual manufacturing and support the Program Manager by determining if proposed projects fit the strategic direction set forth by the Executive Steering Panel. The Board will additionally provide guidance to the Program Manager regarding the feasibility of technical projects and their impact on NAMT resources.

Appendix C

Project Criteria & Review Procedure

Appendix C. Project Criteria and Initial Reviews

Project Criteria

The criteria for determining what constitutes and exemplifies NAMT projects was developed using the results of the two NAMT Workshops held in December 1994 and January 1995 as guides. These workshops identified and documented the types of issues that concern the organizations interested in participating in the NAMT. Additional information in this project development process has been gained through acknowledgment of the NAMT vision, scope, goals, and objectives. All of these elements provide the context for the following description of the NAMT project criteria.

The criteria for describing whether technical projects should be considered as NAMT projects could easily be very large in number, as the NAMT program context encompasses a broad amount of manufacturing-related technologies. The developmental process for producing these criteria proved this possibility to be reality. The process of determining NAMT project selection criteria created over 100 legitimate, "within the context of NAMT," criteria against which a project could be evaluated. This being an unwieldy number, these criteria were grouped, weighted, analyzed, and re-grouped to produce a list of five criteria areas that will provide the primary description of what it means to be a NAMT project. These five criteria areas are listed below:

- **support the NAMT mission,**
- **industrial impact in terms of clearly defined benefits,**
- **provide a complete, specific, and feasible technical plan,**
- **clearly identify industrial participation and commitment,** and
- **define the relationship of the project to the NAMT organization.**

Each of these five project selection criteria areas are defined in detail by additional specific items. These criteria areas and their additional defining elements are summarized in chapter 5.

Project Classification

The five criteria areas listed above, along with the individual specific criteria that further define them, were applied to the fifteen project summaries received in-house at NIST at the time of this plan's development. These criteria were used for evaluating projects on a 100 point scale to determine how well individual technical projects fell within the defined scope and program intent of the NAMT. This process was undertaken in an effort to recommend, only as examples, projects which best demonstrated the NAMT concepts. This process and the initial example recommendations are included in this section.

The application of these five criteria areas was slightly different depending upon what type of project was being evaluated. Before any project was evaluated, it was determined whether the project dealt primarily with NAMT network and DVM infrastructure and enabling technologies; or whether the project was concerned with the demonstration, integration, and operation of a DVM enterprise in pursuit of defined technical objectives; or with a combination of both of these issues. A project that deals with a combination of both issues was classified as the latter type.

The first type of project, which deals primarily with DVM infrastructure and enabling technologies, is termed a DVM Enterprise Infrastructure project. The second type of project, which deals primarily with demonstrating, integrating, and operating a DVM enterprise in pursuit of a real manufacturing objective, is termed a DVM Enterprise Integration and Operation project.

Project Criteria Weighting

For a DVM Enterprise Infrastructure project, the five criteria areas are weighted as follows for project evaluation purposes:

- Support the NAMT Mission: 35 pts.
- Industrial Impact: 15 pts.
- Technical Plan: 30 pts.
- Industrial Participation: 15 pts.
- Definition of Relationship to NAMT: 5 pts.

A brief summary of the rationale for the above point weighting scheme provides that for Infrastructure-type projects, it is most critical that the projects be working on infrastructure technologies that will act as enablers for the Integration and Operation projects; hence, falling within the scope of NAMT is given the most credence. A detailed technical plan was determined to be very close in importance to satisfaction of the NAMT mission. This is followed by industrial impact and industrial participation/commitment, which were weighted equally, yet of lesser importance than NAMT mission satisfaction and the quality of the technical plan. Finally, the NAMT organization role was acknowledged as being worthy of consideration and explanation, as every project must interact in some identified way with the NAMT as a program.

For a DVM Enterprise Integration and Operation project, the five criteria areas are weighted as follows for project evaluation purposes:

- Support the NAMT Mission: 30 pts.
- Industrial Impact: 20 pts.
- Technical Plan: 25 pts.

- Industrial Participation: 20 pts.
- Definition of Relationship to NAMT: 5 pts.

A brief summary of the rationale for the above point weighting scheme provides that for Integration and Operation-type projects, it is most critical that the projects be working on "NAMT" projects, as is explained in Section 5.1. Of next most importance is the need for a good, thorough, and feasible technical project plan. This is followed closely by industrial impact and industrial participation and commitment, which are of equal importance. Note that these two criteria areas are weighted slightly more heavily for this type of project than for an Infrastructure-type project, as they are more critical in the demonstration of a real working enterprise. The last criteria area, again worthy of consideration and explanation, is the definition of the NAMT organization role.

Project Evaluations

A subtotal of 15 project summaries were received at NIST for the NAMT Program at the time of the development of this planning document. Ten of these were submitted by staff of the NIST MEL, and five were submitted by industrial organizations. These 15 project summaries were reviewed by the team of MEL members who were on the IGT and were responsible for developing this section of the NAMT Implementation Plan.

These reviews were conducted, and are included in this planning document, specifically to provide examples of the types of projects that match well with the NAMT project criteria presented here. For these examples, the evaluation process is described below.

All evaluations were conducted independently by the individuals making up the team and consisted of the following process. The team reviewed all the project summaries as a group to determine who would exclude themselves from reviewing which project summaries. An exclusion was required if a team member was either involved in preparing a summary, or would be involved in the conduct of the summarized project. No team member reviewed his own projects. Independently, each reviewing team member then would first read a project summary to classify the project as either a DVM Enterprise Infrastructure project, or a DVM Enterprise Integration and Operation project. After classification, appropriate weights were placed on the evaluation criteria, then points were assigned to each criteria for each proposal. Each team member then submitted his reviews to the team leader, who synthesized the data.

To reiterate, this process was just the first attempt to analyze project summaries based upon quantified, fact-based reason.

Based upon the initial evaluation, it is the recommendation of this sub-group of the NAMT IGT that the following two projects are examples of projects that should be considered as NAMT projects. This is a statement regarding the nature of these project summaries in relation to the developed project criteria. These two projects scored significantly higher in this first evaluation phase than any of the other 13 projects. The two example projects are:

1. The Agile Manufacturing Development of Castings, and
2. The Rapid Manufacture of Complex Geometry Parts in an Advanced DVM Environment.

These two project summaries are included in Appendix C, along with a list of the 13 other project summaries reviewed in this process. Note that additional project reviews from the industry representative members of this sub-group of the NAMT IGT are occurring, and when they are available, these reviews will be combined with those already conducted.

Appendix D

Details of Example NAMT Projects

Appendix D. Details of Example NAMT Projects

This appendix presents the two project summaries that are cited in Chapter 5 of this NAMT document as potential examples of NAMT projects. These project summaries were produced by their respective authors and were received by the NAMT Industry Government Planning Team (IGT) prior to the establishment of any project criteria for NAMT projects.

Project summaries were requested from the staff of the NIST Manufacturing Engineering Laboratory (MEL), and from industry through the NAMT IGT. The objective of this request was to obtain a sampling of technical projects that are driven by industry need and which demonstrate aspects of distributed and virtual manufacturing.

Fifteen project summaries were received and were screened during the NAMT plan developmental process conducted by the IGT. The received project summaries varied greatly in format, since no format specification was announced in the request.

The purpose of including these example project summaries in an appendix is to provide the reader with additional insight regarding the types of projects which could potentially be conducted in NAMT. The two project summaries presented on the following pages were both produced by technical personnel within the NIST MEL. These summaries include all of the technical information, level of effort, and cost data that was submitted to the IGT. No editing of these summary project descriptions has taken place.

Project Listing
In addition to the two summaries presented in this appendix, the following thirteen project summaries were received and screened by the IGT in the development of this planning document. Also, a project summary is included in this list that was received from the Industrial Technology Institute and which is on file, yet was received too late to be included in the screening process for this NAMT document. All these project summaries are on file in the NIST MEL, if additional information regarding a particular project is desired by the reader. Access to this information can be obtained through contacting either the project submitting organization or the NIST MEL. The listing below is in alphabetical order of the project title, and includes the submitting organization.

1. Advanced User Interfaces for the Apparel Production Floor
   - NIST MEL
2. AIAG AutoSTEP Pilot
   - Automotive Industry Action Group (AIAG)

3. Approach to Systems Engineering Framework Technology
   - Technologies Enabling Agile Manufacturing (TEAM) Project
4. Demonstration of Next Generation Continuous Arc Welding for Intelligent Manufacturing
   - NIST MEL
5. Distributed and Virtual Interfaces for NAMT
   - NIST MEL
6. Distributed and Virtual Manufacturing Technology for Advanced Semiconductor Circuits
   - NIST MEL
7. Electronet
   - Westinghouse Electronic Systems
8. High Speed Machining of Aerospace Parts
   - NIST MEL
9. NAMT Assembly
   - NIST MEL
10. NII Applications to Further the Deployment of Agile Manufacturing
    - The Agile Manufacturing Enterprise Forum
11. Precision Rapid Prototyping Using Advanced Materials
    - NIST MEL
12. Shared Databases for Product Development
    - Industrial Technology Institute
13. Systems Engineering Framework for IR Focal Plane Array Design Tools
    - Westinghouse Electric Corporation, University of Maryland, Ontek Corporation for the MADE Program
14. Virtual and Distributed Edge Finishing Research
    - NIST MEL

Title Agile Manufacturing Development of Castings

Contact Ram D. Sriram
Leader, Engineering Design Technologies Group
Manufacturing Systems Integration Division

Clayton Teague
Leader, Micrometrology Group
Precision Engineering Division

Scenario
Participants will demonstrate how network links, common software interfaces and data specifications reduce cycle-time from design to casting acceptance among geographically disparate companies. In this scenario, a large prime manufacturer solicits bids from first tier casting suppliers for the development and validation of a 1000 lb. prototype casting to be delivered for acceptance testing within a four week timeframe. Acceptance of the prototype casting by the prime manufacturer will lead to award of a contract for ten more of the castings to be delivered over a 6 month period.

Here it is assumed that the contract for the prototype casting has already been awarded to a qualified first tier casting supplier. A more elaborate scenario might include the actual bid solicitation process using CommerceNet as the medium for electronic dissemination of the Request for Proposals and for submission of the actual bids. Further, intelligent facilitators will identify appropriate experts (e.g., casting supplier, analyst, etc.). Once the contract has been awarded, the prime manufacturer transmits the design specifications to the casting supplier (either directly or through a shared database). The design specifications detail the material, geometric shape, the dimensions, and the tolerances of the part. The design specification also provides information describing functional intent by way of feature descriptions and parametric equations. The casting supplier is able to correctly interpret the entire design specification because the data is provided according to a STEP Application Protocol providing a common context for interpretation of the design specification.

With the design specification in hand the casting supplier develops several specifications: a design specification for the as-cast part, a preliminary pattern design, a casting process specification, and a machining strategy to machine the desired part from the as-cast part. The pattern design and casting process specification in turn are transmitted electronically to a casting analysis service process maintained on computers at NIST/SIMA's AMSANT facility. Again, accurate information interpretation is achieved by use of common STEP specifications for the design of the pattern and the process description. The pattern design and casting specification will be annotated with audio, video, and textual data and transmitted using one of the commercially available tools (such as Spectragraphics' TeamSolutions^{tm}); thus various team members will have access to engineering intent. The analysis service provided in the AMSANT facility automatically processes the pattern design and process specification and transmits analysis results, such as stress, strain, deflection, and other information, back to the casting supplier. The analysis results are interpreted by the casting process designer and used to improve the process and pattern design. The casting designer may have questions about certain aspects of the analysis. She/he may intiate a video conference with the analyst to discuss potiential conflicts. A shared whiteboard-like mechanism is used to display the design and analysis output, which all the participants can view and comment on. This casting process design, analysis, and redesign cycle is repeated until the desired process performance specifications are achieved.

Once the pattern design and casting process specification have been chosen, the casting supplier electronically transmits the pattern design to another company (say pattern manufacturer) for the machining of the pattern. Again, accurate information interpretation is achieved by use of a STEP Application Protocol. A virtual machining software may provide a simulation of the machining process and how the final product may look like. The pattern manufactuer initiates a video conference and shows this to the pattern designer. If the proposed pattern is acceptable to the casting supplier, the pattern manufacturer generates apppropriate NC machine code for manufacturing the pattern. Before it is delivered to the casting supplier, the pattern manufacturer initiates a video conference and shows the casting supplier various features of the new pattern. The casting supplier accepts the product and it is delivered.

With receipt of the pattern, the casting supplier is now ready to commence the pour. The supplier fully expects that the initial pour will result in an acceptable prototype because the casting process has already been simulated and analyzed using appropriate analysis tools (e.g., grain size, grain distribution, FEA, etc.) available at the AMSANT facility. The pour is finished successfully and the as-cast part is readied for shipping to another company with machining centers of sufficient size to carry out the final machining. The as-cast part is delivered to the company for final machining. This last facility has had ample lead time to set-up for the arrival and machining of this part because the casting supplier had previously transmitted the machining strategy and finished part design specifications. The final machining is performed and the finished part is delivered to the prime manufacturer on schedule.

Having received the prototype casting, the prime manufacturer (who has been a participant in the process all along) now intends to validate the part to ensure that the casting supplier has delivered a part which meets the prime's acceptance criteria. The prototype is subjected to laser scanning and 3D Computer Tomography (CT) scanning or appropriate techniques (e.g., 3D Coordinate measing machines). The laser scans of the surface of the part yield data points describing the exterior dimensions of the part. The CT scans yield data points describing the internal structure of the part. The data which results from the laser and CT scans is transmitted to NIST where scientists, made available through the AMSANT facility, analyze the data points to develop a geometric model of the part as well as to provide analytic results describing the precise dimensional characteristics. The geometric model and analysis report are transmitted back to the prime manufacturer who then compares this information with their original design specifications. The casting supplier's prototype is accepted and the prime manufacturer can now award the contract for the remaining ten castings with confidence.

Goal

The goal of this project is to assist General Electric and its partners with the development and technology transfer of a prototype agile virtual manufacturing process development environment for high quality sand-molded castings.

Manufacturing process development is the largest time and cost element for new product introduction. The manufacturing process development phase covers all work performed to reach a production ready state for a new product design. Current and future market needs along with fierce global competition require major reductions in the manufacturing process development time and cost without quality compromise. Direct speed-up and enhancement of current manufacturing process development activities will not be sufficient to guarantee the competitiveness of U.S. industry. The basic structure for doing manufacturing process development will have to be changed into a virtual one that taps into the best internal and external resources available and utilizes a new operational mechanism that provides major speed and cost advantages.

One of the longest manufacturing development cycles is that for steel castings which can be as long as 2 years. This project addresses renewing and revitalizing the current castings acquisition process for a casting supplier and its sub-tier suppliers and service providers. The project will focus on increasing the manufacturing agility for steel castings that are made using sand molds.

Few software tools supporting casting manufacturing agility are available, and fewer still speak to each other except in their own proprietary languages. As a result, casting manufacturing processes are developed through loosely coupled activities where humans provide the integration, coordination, and most of the information content. These systems lack the agility to respond to the challenges of endless unanticipated changes in product design and market needs.

This project will leverage emerging NII capabilities to improve communications and streamline life cycle interaction, provide electronic documents for information-rich electronic Technical Data Packages, and leverage the collaborators' installed base of tools and techniques by wrapping existing codes, new capabilities, and emerging network services into CAD/CAM/CAE clients. The results are expected to shorten castings development by up to 90%, ensure producible castings and first-part quality, and reduce costs for all participants.

Relationship to MEL Goals

This project pursues technologies which can be used to drive the development of information standards such as those for capturing product data descriptions, design intent, and active engineering documents. In particular it will seek to augment the existing suite of STEP standards with one intended to support the exchange of casting information. These endeavors directly relate to MEL's objectives for promoting the development of the next generation of information standards supporting manufacturing.

This project directly relates to MEL's thrust in Manufacturing Systems Integration through its intention to develop interfaces between existing systems used in the design and analysis of castings and the casting process itself. This project supports the MEL goal of fostering industry development and implementation of advanced manufacturing systems through its efforts to create an agile and virtual manufacturing development process. Casting suppliers, casting service houses, and casting customers will benefit from this project through the establishment of a virtual casting testbed at the NIST AMSANT facility and through dissemination of project results through the NIST facility.

Relationship to NAMT Goals

The Agile Manufacturing Development of Castings project is directly supportive of the NAMT's goal to establish a multi-site, multi-organization distributed and virtual manufacturing testbed. This project will demonstrate how a casting customer, first and second tier suppliers, and casting service consultants can utilize the NII infrastructure, data exchange interfaces, and advanced engineering analysis software to enable rapid development and validation of process and product.

Approach

The project will utilize integration technologies and functional technologies to address the critical need for agile manufacturing development of castings. The integration technologies will include leveraging the use of the NII infrastructure and services to streamline communications between all the life-cycle perspectives required to produce castings. Active document technology which enables rich electronic technical data packages capturing design and manufacturing intent will also be used to facilitate the ease with which specifications are produced, reviewed, and extended.

The functional technologies to be employed are necessary to accelerate and enhance the performance of each stage of the casting manufacturing process development phase. These technologies include those supporting castings producibility analysis, process and pattern design, pattern prototyping, pattern fabrication, process and tooling validation, and networked manufacturing services.

To facilitate technology dissemination, the casting project participants will work with NIST to establish a testbed for castings manufacturing process development technologies. The AMSANT facility at NIST will serve as repository for the specifications and prototype software interfaces developed as part of the project. AMSANT will also serve as a vehicle for testing and demonstrating virtual castings development processes.

NIST Expertise
NIST's MSID has expertise in STEP, collaborative design, databases, knowledge-based systems, systems integration, etc. PED has expertise in high accuracy 3D dimensional metrology.

Benefits to Industry
The distributed and collaborative casting design and manufacturing environment will reduce the castings acquisition process from the current best practice of 12 weeks to 2 to 4 weeks (according to the project team). This will result in considerable savings for both the civilian and the defense sectors.

Industry Participants
Note: Most of the participants here have been identified from a proposal to be funded by ARPA. We hope to obtain their participation in the NAMT initiative.

A. Kader Elgabry
General Electric Corporate Research and Development
Tel: (518) 387-5263
Facilities: Comprehensive engineering laboratory, Concurrent Engineering Toolkit, WWW server, integration utilities, 3D computed tomography equipment for volumetric imaging.
Role: Apply its proven expertise in the development of the Concurrent Engineering Toolkit, active document technology (e.g., engineering design notebooks), software integration, and NII-based applications to the development of the interfaces and mechanisms necessary to link the participants and their capabilities together.

Bill Blair
General Electric Transportation Systems
Tel: (814) 875-2490
Role: Large industry
Facilities: Rapid Prototyping Tool Room includes 16 NC machines, grinding, milling, turning machines and NC programming services.
Role: Large casting customer. GETS is a leading supplier of freight and passenger locomotives and related systems. GETS will assist in cycle testing the virtual manufacturing development process. GETS expects up to 90% reduction in turn-around time from when its casting specifications are released to when the casting is delivered.

Stephen McNeil
United Defense, L.P.
Tel: (717) 225-4781
Role: Large casting customer. UDLP is the Army's primary tracked combat vehicle manufacturer for canon artillery, tank recovery, and combat production lines. Like GETS, UDLP will participate in cycle testing the new development process.

Shrirang Kulkarni
Keokuk Steel Castings
Tel: (319) 524-2661
Facilities: 10 ton Whiting arc furnace, 1 ton and 500 lb. induction furnaces, 1 ton AOD vessel. Complete core room, molding, sand reclamation, heat treatment, cleaning, and finishing facilities.
Role: First tier casting supplier. Keokuk will participate in cycle testing the new development process.

Jiten Shah
Knight & Packer, Inc.
Tel: (708) 505-5722
Facilities: Computer modeling laboratory for CAD, finite element analysis, solidification and mold fill modeling, kinematic analysis, and simulation. Analysis equipment for metallurgical testing.
Role: Second tier supplier engineering services. K&P performs casting design and analysis services for the casting industry. K&P will participate in cycle testing the new process.

Ron Gustafson
Clinkenbeard and Associates
Tel: (815) 226-0291

Facilities: CAD/CAM systems, rapid prototyping using laminated object manufacturing, and 3.5 axis machine centers.
Role: Second tier supplier engineering services. Clinkenbeard performs model and pattern design services for the casting industry. Clinkenbeard will participate in cycle testing the new process.

John Bachinsky
Watervliet Arsenal
Tel: (518) 266-5719
Facilities: 1430 machine tools (260 are CNC); specialized manufacturing capabilities for composites, alloys, large/heavy parts, and long cylindrical parts; rapid prototyping using stereolithography.
Role: Second tier supplier. For this project, the arsenal will perform machining of large castings. It will participate in cycle testing the new process.

Jeffrey Heinen
General Electric Power Generation
Tel: (518) 385-2363
Role: Large casting customer. GEPG will assist in the second half of the project to determine the requirements for scale-up to heavy castings.

David Caldwell
Atlas Foundry
Tel: (206) 473-8724
Role: First tier casting supplier. Atlas will assist in the second half of the project to determine the requirements for scale-up to heavy castings.

Stanley Shelly
National Institute of Flexible Manufacturing
Tel: (814) 333-2415
Role: Regional teaching factory (proximity to GETS). Will serve as a pilot for transferring results to regional technology transfer facilities.

Charles West
BIRL/Northwestern University
Tel: (708) 491-4470
Role: Administrative and financial support for project participants.

Bob Blumberg
Spectragraphics Inc
9107 Waples Street
San Diego 92121
Role: Vendor of groupware products

Other: TBD

Plan

Note: Currently, two divisions (MSID and PED) have been identified as potential NIST collaborators. We hope to involve other divisions at NIST. The following is a tentative plan, and is subject to change.

FY95

- Develop structure for robust casting design specification package
  Deliverable: Robust Design Spec. Templates

- Develop methodology to create/communicate design specifications
  Deliverable: Design Specification Demonstration

- Develop sand-mold casting manufacturability database
  Deliverable: Castability Database

- Develop means for using casting manufacturability database
  Deliverable: Castability Database Demonstration

- Develop modeling capability for faster casting design iterations
  Deliverable: Casting Master Model Demonstration

FY96

- Establish optimized castings design process
  Deliverable: Casting Design Process Demonstration

- Establish enhanced pattern design and fabrication methodology
  Deliverable: Pattern Design Demonstration

- Apply best practices for physical models usage
  Deliverable: Physical Models Demonstration

- Establish rapid validation process for patterns and castings
  Deliverable: Validation Demonstration

- Identify enabling technologies for scale-up to heavy castings
  Deliverable: Applicable Technology Document

FY97

- Define requirements for extending enabling technologies for heavy castings
  Deliverable: Requirements Document

- Transition enabling technology to commercialization organizations
  Deliverable: Evaluation of beta version commercial tools

Budget
Project Duration: 30 months

NAMT PROJECT SUMMARY

The Rapid Manufacture of Complex Geometry Parts in an Advanced Distributed and Virtual Manufacturing (DVM) Environment

Developed and submitted by Divisions 821, 822, 823, and 826
(An integrated scenario involving the MEL hexapod)
January 27, 1995

Scenario: **To demonstrate the capability to rapidly manufacture complex geometry parts in an advanced DVM environment that leverages unique or highly capitalized facilities.**

The manufacture of parts and products which consist of complex geometric features typically entails intensive engineering designs with demanding dimensional tolerances and performance requirements. The manufacture of these parts also involves rigorous manufacturing process engineering that requires systems integration, complex machining processes, and stringent quality assurance systems. Such highly engineered parts and products frequently have multi-tiered supply chains that carry out the functions necessary to transition a part or product from design to market.

In this project scenario, the NAMT will develop a testbed manufacturing enterprise that integrates the manufacturing systems, advanced machining, and advanced metrology capabilities resident at various unique or highly capitalized facilities that are distributed geographically. This testbed manufacturing enterprise will incorporate the electronic exchange of both physical and virtual manufacturing process and product information among the various facility sites. The result of developing and operating this testbed enterprise, which will exist as an advanced DVM environment, will be the demonstrated rapid production of complex geometry parts. This rapid part production demonstration will strive to achieve industry-identified goals of decreased delivery lead time, increased part quality, and decreased manufacturing cost.

The testbed DVM system that is envisioned will include a minimum of three distributed, network-linked nodes, each performing individual functions of the manufacturing enterprise. These nodes include a large industrial corporation, which will establish the criteria for a specific complex geometry part or product based upon design/performance requirements; a supplier, that will provide the process engineering information for the part or product, which will include product and process modeling and simulations; and a manufacturing facility, that will manufacture the prototype or part.

An extremely important aspect of this DVM enterprise is the continuous and concurrent exchange of information among the different nodes to optimize the rapid transition from design to production for the complex geometry part or product. Also, it is important to note that three nodes is the minimum participation, and that there may be additional nodes on the system which will provide expertise in various, specific aspects of the enterprise. Also, it is highly probable that each of this testbed's nodes may have a number of diverse systems linked together which represent the comprehensive capabilities that are required to accomplish that node's particular functional aspects within the enterprise.

Goal

The goal of this project is to develop and demonstrate the capability to rapidly manufacture complex geometry parts in an advanced DVM environment. The project will develop and operate a testbed DVM enterprise that leverages capabilities resident at partner facilities which are unique or highly capitalized. This DVM enterprise will address the manufacture of complex geometry parts from design to production. Quantified goals of cycle-time reduction, quality improvement, and manufacturing cost will be established by the project's industrial collaborators.

Relationship to MEL Goals

This project addresses the MEL goal of anticipating and addressing the needs of the U.S. manufacturing industry for the next generation of physical and informational measurement standards. This will be accomplished by identifying and adapting product data, network and control system interfaces, and performance evaluation parts in a DVM enterprise.

The mission of MEL is to work with the American manufacturing sector to develop and apply technology, measurements, and standards.

A major technical thrust of MEL is in Manufacturing Metrology, specifically in the areas of fast and reliable measurements using high-speed, non-contact CMMs. This project represents the near term physical realization of this MEL technical thrust as a primary element of the Lab's mission. This will be accomplished through the testbed demonstration of these types of measurements made for complex geometry parts using, for example, the MEL Octahedral Hexapod Machine, as verified by MEL's other high-accuracy CMMs. The unique hexapod represents a new class of machine with the potential for precise, high throughput machining and measurement of complex geometry parts.

Another technical thrust of MEL is in Intelligent Machines and Systems, specifically the development and transfer to industry of open architecture controllers. This project will leverage the Enhanced Machine Controller through, for example, a retrofit onto the MEL hexapod, as well as the under-development generic sensor interface for machine controller, to develop and validate the "plug-and-play" capabilities of open architecture controllers.

Another MEL thrust is in Manufacturing Processes and Equipment, specifically relating to high-speed and high-precision manufacturing. An important goal of this project is the demonstration of in-process metrology for sensor-based manufacturing, and will involve technical tasks associated with machine characterization and calibration.

Finally, this project is related to the MEL Manufacturing Systems Integration Thrust, as it will involve the application of simulation technologies, with their associated data exchange requirements, toward the development of this industrially accessible, flexible testbed of integrated manufacturing engineering, machining, and inspection systems. This project will demonstrate a distributed environment through remote network linkages among its industrial and government collaborators.

Use of the MEL hexapod machine is mentioned here as an example of the new types of equipment necessary to meet the challenges of increasing the quality and productivity of complex discrete parts.

More specifics on MEL's focus within this project scenario are contained in the following sections of this project summary.

Relationship to NAMT Goals
The unique, value-added goals of the NAMT to U.S. manufacturing industries are to address the major measurement and interface standards issues associated with developing and demonstrating a national testbed that is an integrated system of DVM. The major focus of MEL in this project will be on the metrology and interfaces required to establish, develop, and operate the DVM enterprise for complex part manufacturing.

Specifically relating to interface and other standards issues, this project will address through testing and development, the following standards:

- STEP:
  identification of resources and application protocols (APs), for product and process data for complex geometries and advanced manufacturing processes;
- Y14 Product Definition:
  application and testing of product geometry and tolerancing information for complex geometries;
- DMIS and CL:

application and testing of interfacing data for inspection and machining from different CAD/CAM- and simulation-based systems;

- Open architecture controller and sensor interfaces:
  development/retrofit and testing of developed interfaces for facilitating "plug-and-play" capabilities among a variety of machine, sensor, and software application types;
- B89, B5 Performance Evaluation for machines:
  application and testing of standard performance evaluation methods for a new class of machine and for high-accuracy CMMs; and
- Electronic Networks:
  application and testing of diverse information sharing using electronic networks.

Specifically relating to metrology, the scope of this project will address the following issues:

- technique development and implementation for in-process metrology for process control and product characterization in the production of the complex geometry parts;
- machine characterization and performance validation for traditional machine tools, high-accuracy CMMs, and the hexapod;
- error compensation of these machines;
- error budgeting and quantification of measurement uncertainties of these machines;
- sensor characterization and calibration;
- structural and thermal machine analysis development based upon measured and simulated data for these machines;
- interim testing procedure development for these machines;

As identified at the NAMT Workshop, the industrially-perceived benefits of the NAMT include standards development; the ability to demonstrate competitiveness and improvement for all industry; access to manufacturing resources; the facilitation of supplier involvement in pilots; the ability to validate process control technology; the development of an independent testbed for accessing new manufacturing processes; the integration of national resources; and the capability to leverage capital equipment and resources. This NAMT scenario project will address all of these perceived NAMT benefits in pursuit of its objectives.

Approach

This collaborative project will achieve its objectives from a collaborative, distributed, virtual, and physical manufacturing enterprise testbed perspective that takes a revolutionary approach to doing business. This approach will develop and apply concepts of DVM, enterprise integration, supply chain integration, collaborative design, integrated product and process development, sensor-based manufacturing, advanced machining, open architecture machine control, sensor integration, machine error compensation, and high-accuracy and in-process metrology, all in pursuit of demonstrating the rapid manufacture of complex geometry parts.

The successful completion of this collaborative project provides the means to improve part quality through sensor-based manufacturing that uses in-process metrology feedback. It will demonstrate reduced production cycle time for complex parts through the elimination of long set-up time requirements for inspection, and then again for machining operations, such as finishing. It will also decrease inspection time.

Ultimately, this project will decrease manufacturing costs by reducing lead time for the quality production of highly engineered parts and products.

The NIST MEL will primarily concentrate on the development of the infrastructure technologies that will enable the development and operation of the DVM enterprise testbed. Specifically, MEL will focus on the metrology and interface standards that will be necessary to use an array of different manufacturing systems in this environment, including traditional machine tools and high-accuracy CMMs; a new class of machine tool, the hexapod; modeling and simulation systems that will provide virtual capabilities; diverse types and sizes of computing platforms; data collection and analysis, and other manufacturing software systems; and open architecture machine controller systems. MEL will leverage its world class metrology and manufacturing expertise for use in the testbed.

The project is envisioned as a 5-year effort that will have active involvement from all of the distributed nodes on the system for all 5 years.

The Advanced DVM Environment

The testbed approach taken in this NAMT scenario project will evolve through the development and operation of an advanced DVM environment. This means that a diverse array of resources, including people, machine tools, computing systems, inspection equipment, and associated manufacturing software will be integrated into a manufacturing system that provides network-linked access to data and information to and from the various nodes that constitute the testbed. This testbed environment will actually be a unified manufacturing enterprise.

The establishment and operation of this DVM enterprise includes elements of both distributed and virtual manufacturing. In a distributed sense, this DVM enterprise involves developing the network links among (and within) the different testbed nodes to facilitate collaborative product and process development and production.

Specifically, this includes linkages for information exchange through the electronic sharing of part and product design plans. This includes the exchange of design, supply, and production schedules, and other electronic commerce data. This includes process engineering information, and quality data feedback. NIST will assist in the establishment of these linkages and in the development and application of the product and process information exchange among the various facilities and systems. Machine programming functions, which will also be networked, will include simulation models of machining operations for optimization purposes.

In a virtual sense, the DVM enterprise operations will integrate modeling and simulation technologies as manufacturing tools. Specifically, this will be performed for machining operations (process modeling), including those conducted on the hexapod. This will include CAD-based CNC and inspection programming, which will be used for data analysis from product inspection, and will place special emphasis on the use and simulation of in-process metrology feedback for process control. Also, modeling and simulation technologies will be rigorously applied to design analyses.

Also included in the DVM environment is the establishment of inspection network links among the industrial collaborators and the MEL node to assist in the verification of industrial and testbed quality assurance practices. The inspection network links among the different facilities and within MEL will provide sensor-based process monitoring capabilities from in-process metrology, with emphasis placed on the demonstration of this technology, and they will also provide post-process quality checks.

To reiterate, the focus of MEL in developing and operating this advanced DVM environment will be on the infrastructural technologies and standard interfaces required to enable this enterprise.

Industry Participants

Potential industrial and government agency participants in this project and their areas of interest follow.

-Large Industry: *General Motors Powertrain Division*, Toledo, OH: the manufacture of and metrology for precision automotive gears and gearing assemblies, and automobile transmissions.

-Supplier: *Eaton Corporation*, Cleveland, OH: the manufacture of and metrology for precision automotive gears, gearing assemblies, and precision castings.

-Large Industry: *Caterpillar Inc.*, Peoria, IL: the manufacture of and metrology for precision automotive gears, gearing assemblies, and heavy equipment.

-Supplier: *United Technologies Research Center/Pratt & Whitney*, East Hartford, CT: the manufacture of aircraft jet engines and components.

-Government: *NIST Manufacturing Engineering Laboratory*, Gaithersburg, MD: development of octahedral hexapod machine's control systems, complex machining, and in-process metrology for complex part manufacture; product and process data exchange; high-accuracy CMMs and manufacturing metrology; integration of manufacturing systems; manufacturing standards; sensor-based manufacturing.

A potential realization of the scenario described previously in this project summary could pertain to the rapid production of transmission components for automotive applications. In such a scenario, the large industry, GM Powertrain, and the supplier, Eaton, would constitute nodes in the DVM enterprise, along with the manufacturing facility, the NIST MEL. Such an enterprise would not be limited to these nodes, yet could conceivably achieve the NAMT objectives with the participating facilities.

Also, organizations working in related areas with whom NIST has working relationships, include the following:

-Large Industry: *Boeing Commercial Aircraft*, Everett, WA: airframe manufacture and assembly.

-Large Industry: *McDonnell Douglas Aerospace*, St. Louis, MO: the manufacture and assembly of aircraft components and airframes.

-Supplier/OEM: *Giddings & Lewis/Sheffield Measurement*, Dayton, OH: the development of the next generation coordinate measuring machine.

-Supplier/Vendor/SME: *ICAMP, Inc.*, Bolton, CT: CAD-based inspection of complex geometry parts.

-Supplier/OEM: *Brown & Sharpe*, North Kingstown, RI: high-accuracy coordinate metrology systems.

-Supplier/OEM: *Ingersoll*, Rockford, IL: production of machine tools and the hexapod.

-Government: *Oak Ridge Centers for Manufacturing Technology/Martin Marietta Energy Systems*, Oak Ridge, TN: virtual and distributed manufacturing demonstrations, gear metrology, and open architecture machine controllers.

-Government: *Defense Logistics Agency Defense Construction Supply Center*, Columbus, OH: the procurement and warehousing of precision helicopter gears for Defense helicopter applications.

-*Consortium:* *For Non-Contact Gauging, the Ohio Aerospace Institute*, Cleveland, OH: the development of a flexible, high-speed, high-accuracy measurement system based on optical sensors and an integrated control system for aerospace manufacturing applications (a current NIST ATP Project, working with Division 821).

-*Consortium:* *Auto Body, consisting of Ford, GM, and Chrysler*, Detroit, MI: dies for sheet metal stamping used in automotive structural and body panels, molds for precision castings, and molds for injection-forming.

-*Consortium:* *Next Generation Inspection System, National Center for Manufacturing Sciences*, Ann Arbor, MI: development of advanced sensors and controls for high-speed, flexible, inspection for automotive and aerospace manufacturing applications.

It is not possible at this time to detail the nature of each collaborator's contribution in terms of financial and other resource provision, but the organizations mentioned above have all expressed interest in working with NIST in the areas listed, all of which fit in with this proposed project. It will be part of the NAMT and this project's planning process to develop in more detail specific application projects based upon the identified industrial needs.

Technical Plan
There are two major portions of this project's technical plan: establishment and operation of the DVM enterprise testbed as a collaborative scenario, and development of the MEL testbed node.

The summary below schedules the completion of the objectives associated with the establishment and operation of the DVM enterprise. The approach taken to achieving these objectives has been detailed in previous portions of this document.

Year One Milestones
1. Network links of all systems at MEL node complete.
2. Identification of NIST staffing.
3. Identification of industrial nodes, their roles, and their resource contributions.
4. Identification of specific part and geometry types to demonstrate in the DVM enterprise.
5. Identification of specific manufacturing improvement targets.
6. Identification of machines, sensors, and other systems to be included in the DVM enterprise.

Year Two Milestones

1. Network links of all systems among industrial and other government nodes complete.
2. DVM enterprise demonstration part design requirements completed and electronically distributed.
3. Demonstration of initial information exchange capabilities among enterprise nodes.

Year Three Milestones
1. Design of DVM enterprise demonstration part completed.
2. Design information for demonstration part electronically distributed.

Year Four Milestones
1. Process engineering for demonstration part completed.
2. Process engineering information for demonstration part electronically distributed.
3. Virtual/distributed CNC programming for production demonstrated.
4. Virtual/distributed inspection programming demonstrated.
5. Virtual/distributed process monitoring demonstrated.

Year Five Milestones
1. Demonstration of inspection data feedback for process control in the production of the demonstration part.
2. Demonstration of distributed and virtual manufacture, inspection, and process control for the production of the demonstration complex geometry part.
3. Documentation of benefits.

In addition to the DVM enterprise objectives, the technical plan for developing the MEL testbed node in pursuit of these objectives should also be detailed here. The MEL testbed node technical plan consists of five primary functions to be conducted by MEL. These functions are standards testing and development, system performance measurement, metrology application, systems integration, and process simulation. The MEL testbed node will function as a Laboratory-wide node, which explicitly indicates participation from all four technical research Divisions of MEL, plus support from the Fabrication Technology Division. The following summarizes the work tasks in the MEL testbed node technical plan, with an indication of the lead MEL Division for each task.

Standards Testing and Development: (see additional details in "Relationship to NAMT Goals" section of this document)
- STEP, *Division 826.*
- Y14 Product Definition, *Division 826.*
- DMIS, *Division 821.*

- CL, *Division 823, 822.*
- Open Architecture Controller and Sensor Interfaces, *Division 823, 822.*
- B89, B5 Performance Evaluation of Machines, *Division 821, 822.*
- Electronic Networks, *Division 826.*

System Performance Measurement:

- Definition of performance metrics for DVM enterprise, *Division 821, 822, 823, 826.*
- System instrumentation, *Division 821, 822, 823, 826.*
- Data collection and analysis, *Division 821, 822, 823, 826.*

Metrology Application: (see also "Relationship to NAMT Goals" section of this document)

- Performance validation and calibration of machines, including hexapod, *Division 822, 821.*
- Error compensation of machines, including hexapod, *Division 821, 822.*
- Quantification of measurement uncertainty of machines, including hexapod, *Division 821, 822.*
- Sensor characterization, *Division 821, 822, 823.*
- Data collection for process capability models, *Division 821, 822.*
- Structural and thermal analyses of machines, including hexapod, *Division 822, 821.*
- Interim testing development for machines, including hexapod, *Division 821, 822.*
- In-process metrology development for process control and product characterization, *Division 823, 822, 821.*

Systems Integration:

- Enhanced Machine Controller (onto hexapod), *Division 823, 822.*
- Network nodes, among facilities and within MEL, *Division 826.*
- Multiple and diverse sensor systems, *Division 822, 823, 821.*
- Control algorithms for machining and inspection, *Division 822, 826, 823, 821.*
- Simulation systems, including CAD-based inspection, CNC programming, design analysis, *Division 826, 822, 823, 821.*
- Machine software error compensation, *Division 822, 823.*
- In-process inspection data feedback for machine control, *Division 823, 822.*
- Micro-positioning of machines, including hexapod, *Division 823, 822.*

Process Simulation: (see also "The Advanced DVM Environment" section of this document)

- Process modeling of machining operations, including the hexapod, *Division 822, 823.*
- CAD-based inspection and CNC programming, *Division 821, 822, 823, 826.*
- Data analysis for in-process metrology, *Division 822, 823, 821.*
- Process monitoring through in-process metrology feedback, *Division 823, 822, 821.*
- Design Analysis, *Division 826, 822, 821, 823.*

Budget

This project as it is summarized is a cross-divisional effort that includes participation from all four MEL research Divisions during each year. Also, the Fabrication Technology Division will provide machining support and technical assistance over the duration of the effort. Based upon the summarized tasks, it is estimated that this project will conservatively require ten to twelve manyears of effort per year within the Lab, or roughly three manyears per Division. This would translate into the following budget.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Division 821	$600K	$600K	$600K	$600K	$600K	$3.0M
Division 822	$600K	$600K	$600K	$600K	$600K	$3.0M
Division 823	$600K	$600K	$600K	$600K	$600K	$3.0M
Division 826	$600K	$600K	$600K	$600K	$600K	$3.0M
TOTAL	$2.4M	$2.4M	$2.4M	$2.4M	$2.4M	$12.0M

Additional DE requirements: $250K/yr.

Cross-Division Participation

This has been detailed throughout this document and will be refined during additional planning. Related on-going efforts within MEL include the Enhanced Machine Controller Project, the Complex 3-D Metrology Laboratory Project, the Sensor Interface for Machine Controller Project, the Next Generation Inspection System Project, SIMA, NIIP, the Deployment of the Kinematic Interim Testing Artifact Project, and the ATP Project with the Ohio Aerospace Institute (PED connection).

It is estimated that on-going related efforts within MEL represent approximately $1.0M-$1.5M of funding.

There also exists the potential for cross-laboratory participation in this project involving the Statistical Engineering Division of CAML, and CSL, which will be defined in future planning.

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- Measurement Services
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- Metallurgy
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- Systems and Network Architecture
- Advanced Systems

Computing and Applied Mathematics Laboratory
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- Statistical Engineering[2]
- Scientific Computing Environments[2]
- Computer Services
- Computer Systems and Communications[2]
- Information Systems

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[1]At Boulder, CO 80303.
[2]Some elements at Boulder, CO 80303.

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