NGMS NEXT GENERATION MANUFACTURING SYSTEMS

Intelligent Manufacturing Systems (IMS)

NGMS-IMS project Phase III

Synergistic Integration of Distributed Manufacturing and Enterprise Information

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Final Report

Project Sun-Set

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Prepared by

The Next Generation Manufacturing Systems IMS Project

Consortium for Advanced Manufacturing – International Inc. (CAM-I)

International Coordinating Partner

NGMS IMS PROGRAM OFFICE

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Executive Summary

Introduction

The Consortium for Advanced Manufacturing International (CAM-I) is an international not-for-profit collaborative research organization. Its research Programs have been on the cutting edge of technology for the past 27 years and have literally changed the face of modern industry. NGMS is one of CAM-I's major international initiatives. An international group was formed under the auspices of CAM-I to consider the requirements for Next Generation Manufacturing Systems (NGMS). This group has concluded a successful nine-year research and development NGMS-IMS project Phase I, II and III efforts under the Terms of Reference (ToR) of the international IMS (Intelligent Manufacturing Systems) program.

NGMS Vision

The future for manufacturing lies with new forms of manufacturing strategies based on global networks of self-organizing, autonomous units. These units may be part of one company, located globally or part of several companies, all co-operating to address customers' requirements (extended and virtual enterprises).

These networks of companies (or demand chains) need to rapidly adapt to changing requirements, new technologies, merging of existing technologies and increasing globalization. The required shorter response times will not allow time for experimentation and iteration with the physical products and processes. Thus the entire enterprise must be modeled and simulated prior to actual operation allowing alternatives to be quickly developed and evaluated. To be effective the simulation systems must use the logic and design of the physical processes and thus form the core of the production process systems. This requires new forms of modeling systems, simulation systems, communication and information exchange systems.

The NGMS Phase I and II projects resulted in a vision of the Next Generation Manufacturing Enterprise (NGME) and significant modeling and simulation developments based on the concepts of autonomous & distributed manufacturing systems, biological manufacturing systems, Fractal Company and agile manufacturing.

At the conclusion of Phase II, it was realized that the results actually defined the scope of the **“Digital Factory”**. Typical Digital Factory concepts include:

- Within the Digital Factory production simulations and the simultaneous design of both product and production processes can be employed to reveal potential errors and/or conflicts at an early facility design stage.
- Utilizing the concept of the Digital Factory, the factories of an NGME can be truly designed and simulated within a virtual computer network.
- Within this Digital Factory simulation, the factory performance can be simulated before cutting any metal or turning any earth for the factory, which, in turn, could result in timesaving of up to 30 percent in the factory start-up and operation.

The Digital Factory concept were addressed in all aspects of the NGMS-IMS project Phase III research and development activities. The Phase III NGMS-IMS project partners came from Europe, South Korea, Switzerland and the United States and, in most cases, they were involved in both the NGMS-IMS project Phase I and II efforts.

Objectives

The objective of the NGMS-IMS project Phase III effort was to develop the best ideas on advanced manufacturing systems within the context of the Digital Factory and integrate them into the Next Generation Manufacturing Systems (NGMS). The key issues of NGMS had to do as much with the integrability of manufacturing technologies and processes as with the technologies and processes themselves.

The NGMS-IMS Phase I and II projects established a framework for the Phase III project where the project partners performed a set of short range Tasks that were completed in early 2005.

Accomplishments were as follows:

- Developed a unifying description of NGMS, and continued the on-going development of NGMS Characteristics and Requirements to capture the results of the individual R&D activities, and developed a framework for ensuring the integrability of the results into a cost-effective NGMS that is operating within an NGME.
- Developed an integratable set of models and simulators merging a bottoms-up view of the factory floor as found in NGMEs with a top-down view of the globally distributed virtual enterprises that constituted those NGMEs. The basic concept of the Digital Factory was defined and the research and development direction and industry test cases of the project were engaged.

Benefits

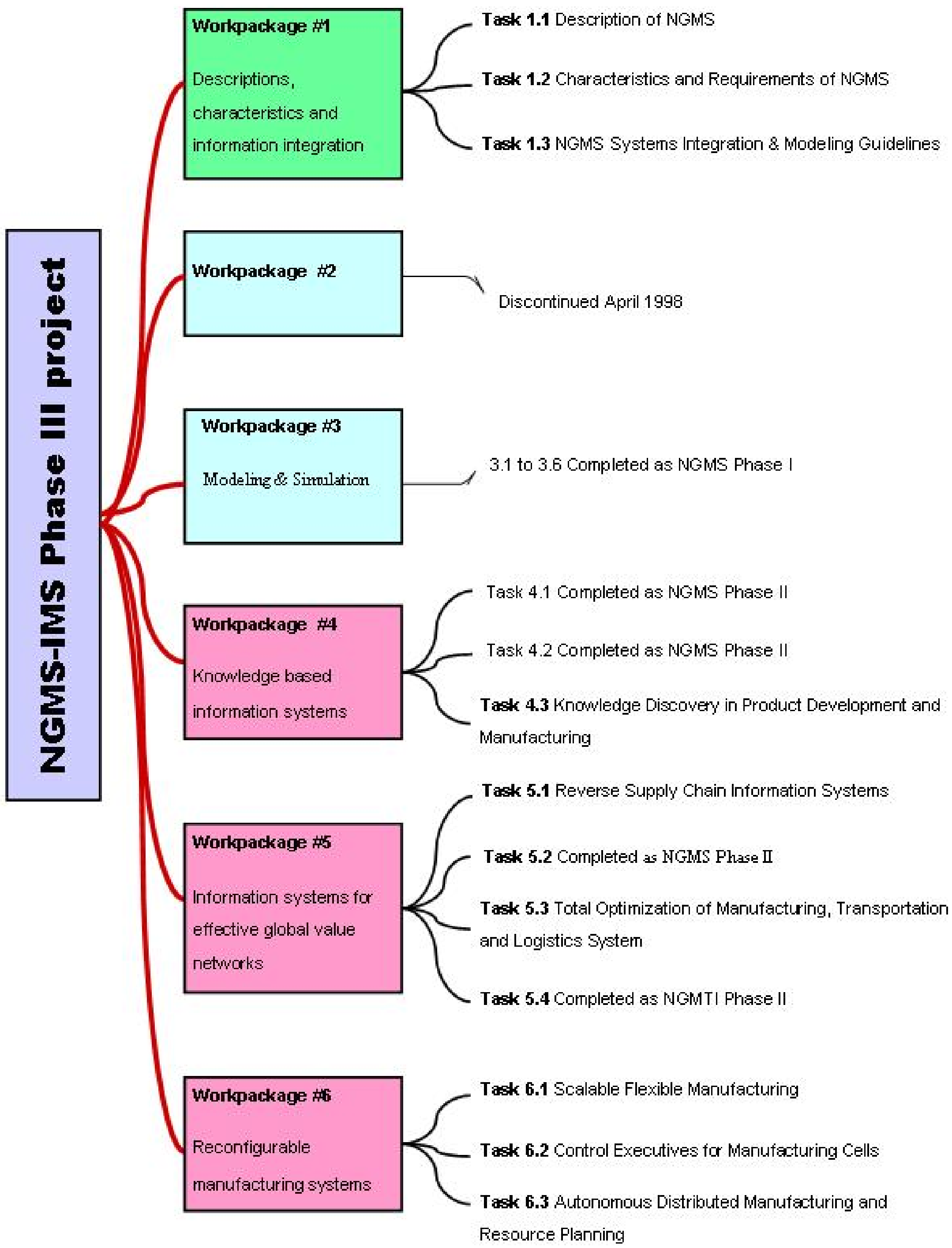
The overall benefit of adopting the NGMS ensured survival and future prosperity of the project partners, nothing less. However, during the process of change the NGMS-IMS Phase III project provided partners with the following more specific benefits:

- Working on future manufacturing issues together led technologists and companies in USA, South Korea, Switzerland and Europe who were addressing similar problems.
- A valuable shared learning experience on the latest technological developments in manufacturing systems and their applications that minimized a company’s investment exposure in research and development without “reinventing the wheel”.

- A framework and blueprint for the integration of future manufacturing systems into the new forms of manufacturing enterprises.
- Competitive advantage from a more rapid adoption of advanced systems, processes and technologies.
- More rapid and “right-first-time” establishment of networks of autonomous units through the application of new types of simulation methodologies and tools.
- More rapid and “right-first-time” establishment of manufacturing processes through the application of new types of simulation methodologies and tools.
- Greatly improved response times to changing customer needs through the adoption of new forms of modeling and simulation systems.

Project Workplan

Four major research and development areas were incorporated in the NGMS-IMS Phase III project. These, together with their attendant Tasks are summarized in the following diagram:


NGMS-IMS Phase III project
Workpackage #1
Descriptions, characteristics and information integration
Task 1.1 Description of NGMS
Task 1.2 Characteristics and Requirements of NGMS
Task 1.3 NGMS Systems Integration & Modeling Guidelines
Workpackage #2
Discontinued April 1998
Workpackage #3
Modeling & Simulation
3.1 to 3.6 Completed as NGMS Phase I
Workpackage #4
Knowledge based information systems
Task 4.1 Completed as NGMS Phase II
Task 4.2 Completed as NGMS Phase II
Task 4.3 Knowledge Discovery in Product Development and Manufacturing
Workpackage #5
Information systems for effective global value networks
Task 5.1 Reverse Supply Chain Information Systems
Task 5.2 Completed as NGMS Phase II
Task 5.3 Total Optimization of Manufacturing, Transportation and Logistics System
Task 5.4 Completed as NGMTI Phase II
Workpackage #6
Reconfigurable manufacturing systems
Task 6.1 Scalable Flexible Manufacturing
Task 6.2 Control Executives for Manufacturing Cells
Task 6.3 Autonomous Distributed Manufacturing and Resource Planning

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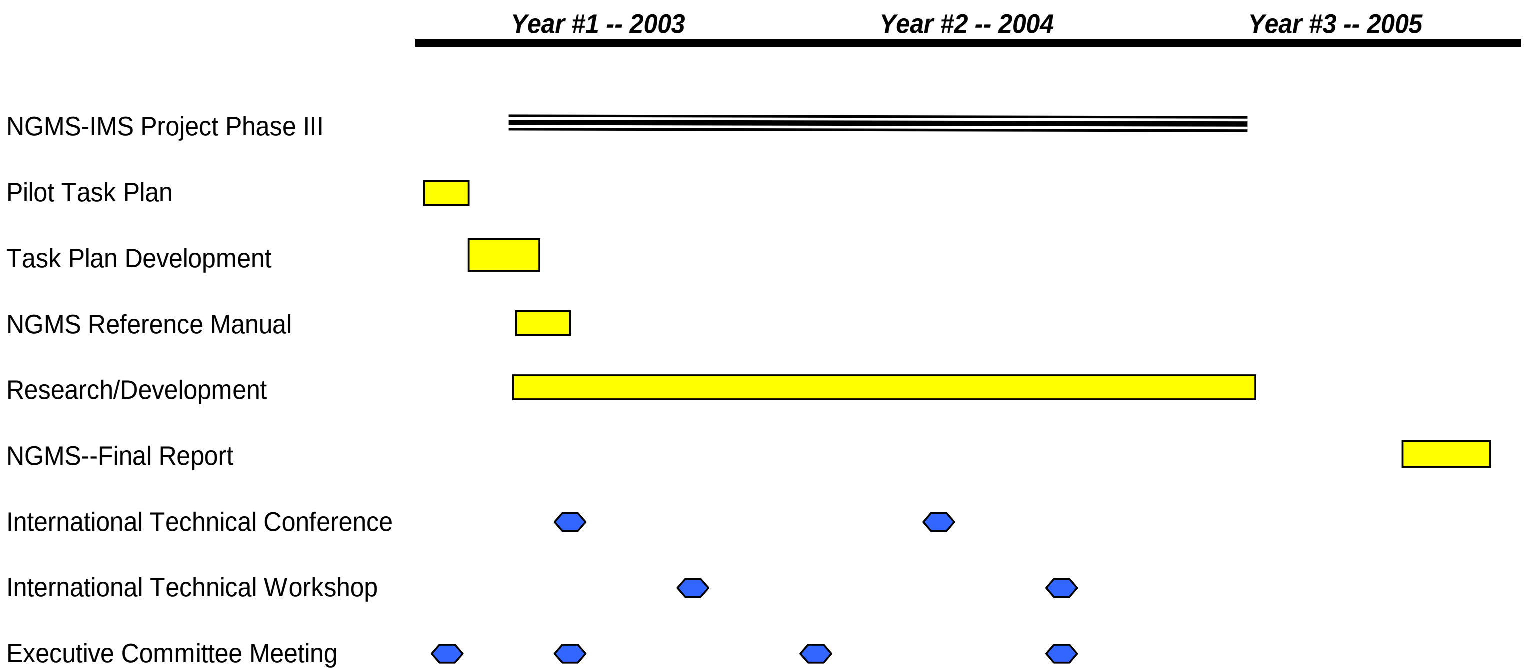
Project Master Schedule

NGMS-IMS project Phase III was initiated on 1 April 2003 and completed its research in early 2005.

The following Gantt chart shows the main timelines, workshops and technical conferences.



Operating Principles

The NGMS-IMS Phase III project operated within a set of basic principles, which are summarized as follows:

- The maximum benefit for project partners was achieved by collaborating and working together with companies in other regions around the world. Thus the entire NGMS-IMS project Tasks were international with participants from Europe, USA, South Korea, and Switzerland.
- Each company undertook research in one or more of the project Tasks areas and funded their own research along the way. By working

together the participants significantly leverage their own investment in time and money and minimize risk.

- Each project partners received the results from each and every Workpackage and Task.
- Each partner company paid an annual participation fee to join NGMS project. This fee provided for the following:
    - International project management, co-ordination and direction under the NGMS project research “umbrella”.
    - NGMS conferences, workshops and meetings
    - NGMS private web site for discussion forums and proprietary reports
    - Contacts with companies worldwide
    - Simple resolution and management of the Intellectual Property Rights in NGMS.

0. Preface

The NGMS-IMS project has evolved from the four-year Phase I effort, completed on 31 March 2000, and the three-year Phase II effort, completed on March 31, 2003 into a Phase III effort that was initiated on 1 April 2003.

1. Project Summary

1.1 Introduction

An international group was formed under the auspices of the Consortium for Advanced Manufacturing International (CAM-I), to consider the requirements for Next Generation Manufacturing Systems (NGMS). The purpose of the earlier IMS Phase I and II projects was to propose and conduct pre-competitive research and development activities under the Terms of Reference (ToR) of the international IMS initiative.

The research and development efforts that were completed in the Phase I and II project resulted in a vision of the Next Generation Manufacturing Enterprise (NGME). This vision was based on the NGMS technical agenda that described a set of technology and systems research and development activities that were required to take the first step towards realizing an NGME. As the NGMS-IMS project research and development activities were completed within the Phase I and Phase II projects it was realized that the results that were obtained actually defined the scope of the “Digital Factory”.

Within a Digital Factory, production simulations and the simultaneous design of both product and production processes can be employed to reveal potential errors and/or conflicts at an early facility design stage. The facility simulations can also dramatically shorten the expensive period of production start-up, which often lasts for several months. Further, utilizing the concept of the Digital Factory, the factories of an NGME can truly be designed and simulated within a virtual computer network. Within this Digital Factory simulation the factory performance can be simulated before cutting any metal or turning any earth for the factory, which in turn could result in timesaving of up to 30 percent in the factory start-up and operation.

During the first twelve months the NGMS-IMS Phase III project partners held a series of Regional meetings (Switzerland, South Korea, Europe and USA) as well as an International Workshops to develop the structure for the Next Generation Manufacturing Systems (NGMS) Phase III efforts. Within the context of the Workpackages that the partners developed, the basic concept of the Digital Factory has been employed.

This effort resulted in the refinement of the NGMS-IMS project direction for Phase III, where the Digital Factory concept was addressed by the project partners in each aspect of the projects research and development activities.

1.2 Objectives this Project

The unique strength of the NGMS-IMS project was, and has been, its ***systems approach***. Starting with the NGME vision, the NGMS-IMS project adopted a needs-based understanding of the characteristics of future manufacturing systems. The objective of the NGMS-IMS project Phase III effort was to develop the best ideas on advanced manufacturing systems within the context of the Digital Factory and integrates them into the Next Generation Manufacturing Systems (NGMS). The key issues of NGMS had to do as much with the integrability of manufacturing technologies and processes as with the technologies and processes themselves.

The technical agenda that was described within the NGMS-IMS project Phase I and II efforts remained basically the same for the Phase III efforts and was defined as a set of Tasks that were far-reaching, with research and development grouped into seven categories:

1. NGMS Description, Requirements, Technologies, and Integration
2. Modeling and Simulation for NGMS
3. Data Models
4. Planning, Scheduling, and Control Systems
5. Integrated operations
6. Intelligence in the Work Unit
7. Enterprise Dynamics.

These seven categories described the Tasks the NGMS-IMS project partnership were undertake to fill in the vision for Digital Factory and the actual manufacturing systems that will be employed in the early 21^{st} Century.

This NGMS-IMS project established a framework for a set of short range Tasks that were completed by early 2005. Specifically, it:

- Developed a unifying description of NGMS, continued the on-going development of NGMS Characteristics and Requirements to capture the results of the individual R&D activities, and developed a framework for ensuring the integrability of the results into a cost-effective NGMS that is operating within an NGME.
- Developed an integratable set of models and simulators merging a bottoms-up view of the factory floor as it will be found in NGMEs with a top-down view of the globally distributed virtual enterprises that will constitute those NGMEs.
- The basic concept of the Digital Factory were defined through research and development direction and industry test cases that the project engaged in during the three year project.

2. BACKGROUND AND STATE OF THE ART

The twenty-first century has seen a truly global economy based on the evolutionary merging of the world's regional trading areas. Rising standards of living throughout the world have lead to global distribution of strong markets and of capital formation. Rising standards of education have lead to skilled work forces in all regions. High bandwidth, multi-media communication has lead not only to *global villages* but also to *global enterprises* and even to *global societies*.

The future for manufacturing lies with these new forms of manufacturing strategies based on global networks of self-organizing, autonomous units. These unites may be part of one company (legal entity), located globally, or part of several companies, all co-operating to address the customers' requirements. Whether it is one company or a network of several companies (an extended or virtual enterprise) demands on the manufacturing systems will be very different from those in use today.

These networks of companies need to rapidly adapt to changing requirements, new technologies, merging of existing technologies and increased globalization. Shorter response times will not allow for experimentation and iteration with the real thing; the Digital Factory concept will be utilized to simulate each new product and process. The grouping of autonomous units must work at their optimum from the start, where all decisions will be made on the basis of modeling and simulation, rather than build and test methods.

These Next Generation Manufacturing Enterprises (NGMEs) will evolve from today's restructured and re-engineered enterprises. The intelligent enterprises will be focused on selected markets by exploiting their high value and core competencies. The Extended and Virtual enterprises, formed by alliances will dynamically form networks of real companies, which have merged their core competencies to produce complex products and systems with the following important elements:

- NGME's are customer-driven. Except for the most routine of commodity products and customers they will be deeply integrated into all aspects of the product lifecycle.
- Suppliers will be totally integrated into the product cycle. Sub-system suppliers will also be included, especially, peers in the manufacturing enterprise.
- Rigid, static, hierarchical, manufacturing enterprises will be replaced by virtual Digital Factory enterprises exhibiting great adaptability to rapid change that will be able to produce small product lots with high quality and at a low cost.
- NGMEs will be made up of relatively simple, distributed, autonomous but cooperating work units, working to agreed-upon targets in flattened, network-like, organizations. The autonomy of the work units will be extend to each having profit and loss responsibilities.

The global economy and the technologies for tele-collaboration will require and enable work units to be distributed globally, resulting in, for the successful NGME an optimum blend of customer relationship, development and manufacturing expertise, quality, costs, and post-sales activity for customers anywhere in the world.

To support this changing manufacturing environment the partners in this NGMS-IMS project represented the best thinking along four different perspectives on advance manufacturing systems. These perspectives had the same ultimate vision for NGMS and each contributed in various ways and at different times to the realization of the vision.

They where:

- Agile Manufacturing
- Autonomous Distributed Manufacturing Systems (Reconfigurable Manufacturing)

- Biological Manufacturing Systems
- The Fractal Company

As these concepts are underlying and offer different perspectives of maturity, each contributed toward the unified view of NGMS project.

3. Project Objectives, Results, and Overview

3.1 Objectives and Industrial Relevance

The NGMS-IMS Phase III project partners believed that to be competitive in the early 21st Century, they must endorse the perspectives outlined in Section 2.0. With the NGMS-IMS project technical agenda developed in a series of consensus-building workshops by the project's industrial partners a set of Tasks were described that provided the systems technologies needed for the advanced manufacturing systems.

The framework for this project was defined through a set of Tasks that were completed by April 2005 as follows:

- Developed a unifying description of an NGMS, that begin with the on-going development of the NGMS Characteristics and Requirements that were captured from the results of the individual research and development activities, and finally, developed a framework for ensuring the integrability of the Task results into a cost-effective NGMS.
- Developed an integratable Digital Factory with development of a set of models and simulators that merged a bottoms-up view of the factory floor as found in the NGMEs with a top down view of the globally distributed virtual enterprises that constituted those NGMEs

3.2 Major Results and Advances in the State-of-the-Art

The major results of this NGMS-IMS project were built upon the results of the Phase I and II efforts and integrated into the Phase III efforts as follows:

- Build upon and further developed the unified description, Characteristics and requirements of Next Generation Manufacturing Systems (NGMS) developed in Phase I and II.
- Developed a framework for integration of globally distributed manufacturing systems made up of autonomous work units.
- Developed and refined Digital Factory reconfigurable manufacturing system models for the enterprises that were made up of a number of autonomous and distributed work units. These models considered shop floor, factory, and enterprise issues and the linkages among levels and functions.
- Enhanced the application of the Model Based Enterprise (MBE) as it related to concurrent process and technology development to support manufacturing.

The results from this project advanced the understanding of the nature of Next Generation Manufacturing Systems in a way that the NGMS project provided benefit throughout the product lifecycle, and eliminated the technological barriers.

3.3 Scope and International Dimensions

This NGMS Phase III project had as its technical scopes the research and development of new systems methodologies and technologies for Next Generation of Manufacturing Systems. ***Manufacturing systems*** were those that supported product definition, design, production, distribution, maintenance and field enhancement, and recycling and/or disposal. The project partners came from Europe, South Korea, Switzerland, and United States Regions; where each region was expected to play a key role.

Tasks were accomplished primarily as cross-regional activities; however, there were a limited number of Tasks that were Regional only. Were a Task was Regional only a liaison representative from the other Regions was assigned as necessary.

3.4 Project Overview and Approach

Work toward the goals of this project was underway under the NGMS-IMS project structure (See Section 5.1). The project had participation from the Europe, South Korean, Switzerland and the U.S. Regions. The NGMS-IMS Phase III project actively recruited additional industrial Partners in each of the regions as well as SME's (See Section 11.0).

3.5 Technical Themes

This NGMS-IMS Phase III project addressed, in an integrated way, many of the technical themes that had been identified by the International IMS as follows:

IMS Technical Theme	Impact
Total Product Life Cycle Issues	o Future general models of manufacturing systems
Process Issues	o Technology innovation in manufacturing processes o Improvement in the flexibility and autonomy of processing modules that compose manufacturing systems o Improvement in interaction or harmony among various components and functions of manufacturing o Scalability of flexible manufacturing systems
Strategy/Planning/Design Tools	o Methods and tools to support business process re-engineering o Modeling tools to support the analyses and development of manufacturing strategies o Design support tools to support planning in an extended enterprise or virtual enterprise environment
Human/Organization/Social Issues	o Improved capability of manufacturing workforce education, training o Autonomous offshore plants o Corporate technical memory
Virtual/Extended Enterprise Issues	o Methodologies to determine and support information processes and logistics across the value chain in the extended enterprise.

IMS Technical Theme	Impact
	o Architecture (business, functional and technical) to support co-operation across the value chain, e.g. concurrent engineering across the extended enterprise o Team working across individual units within the extended enterprise.

4. PROJECT WORKPLAN

4.1 International Cooperation

To initiate this NGMS-IMS project Phase III effort a series of Regional meetings and an International Workshop were conducted in which the key characteristics of NGMS were identified. It was determined that the partners contribute complimentary views to the realization of this NGMS-IMS Phase III project in the four major research and development areas identified under the Workpackages definitions that follow.

The research and development areas of interest logically lead to similar systems approaches; although, each area emphasizes a different set of issues and characteristics. By combining the concepts it was possible to accelerate the development of a more competitive, complete, and comprehensive systems solution. It provided for a global test bed for the NGMS Digital factory concept, followed by the validation and then the testing of the technologies that address such issues as cost, timeliness, flexibility, robustness, and scalability of a globally distributed NGMS.

4.2 Workpackage #1 -- Descriptions, Characteristics, Requirements and Information Integration

4.2.1 Scope and Objectives

This Workpackage provided the framework for the NGMS-IMS project.

- Task 1.1 contained the description of NGMS and it evolved from the NGMS-IMS project Phase I and II efforts. The descriptions were incorporated into the Characteristics and Requirements of the NGMS.

- Task 1.2 contained the Characteristics and Requirements of NGMS.
- Task 1.3 continued to ensure that the guidelines used (e.g., object-oriented modeling) within Workpackages 4, 5 and 6 were consistent and that the resultant simulators and models present a consistent representation of the NGMS.

Within this Workpackage the principle objectives were as follows:

- Built a comprehensive and unified description of an NGMS with clear definitions that were cross-referenced to the concepts that were developed in the NGMS-IMS project Phase I and II efforts.
- Developed and maintained the NGMS Characteristics and Requirements so that the NGMS-IMS Phase III project had an increasingly rich, complete, and consistent vision of an NGME.
- Provided guidelines for system modeling tools across the tasks within Workpackages 4 through 6.
- Guided the efforts of the NGMS-IMS Phase III project Executive Committee in maintaining consistency across each of the other NGMS-IMS project Workpackages and their Tasks.
- Operated at the Strategic end of tactical planning.
- Established "Links" with software vendors in identified Task areas.
- Obtained Task(s) intent of tools that were disseminated to NGMS program Task teams.

The NGMS-IMS project documents are available to project partners only and will not be distributed to the public. During the execution of the project documents were generated and posted on a project Website for access by all partners. This project Website has been shut and no project information is available to the public.

4.2.1.1 Tasks, Deliverables, Schedules and Participants

Task 1.1 Description of Next Generation Manufacturing Systems

This Task continued to provide a standard description of an NGMS, with key words defined and key concepts described. A cross-Regional Task team updated the detailed description of NGMS using the four central concepts augmented with additional ideas on advanced manufacturing systems. Further, they examined the central ideas for commonality and for differences. Where different words were used to describe similar concepts, the Task team provided a mapping so that there was a shared understanding of the vocabularies used to articulate the concepts.

The Task team made visible any major differences among the concepts contributing to a NGMS.

Deliverables

- Preliminary and Final Reports describing an NGMS in hardcopy and available on the Internet.
- Presentations of the NGMS Description at NGMS and non-NGMS meetings and conferences to obtain consensus of all project partners.

Schedule

April 2003	Task team formation
September 2003	First draft of Workpackage and Task Documents
April 2004	Present draft to membership at the International Workshop
June 2004	Release draft of document for NGMS-IMS project
September 2004	Final review of Workpackage proposal
December 2004	Update Tasks and Workpackage documents
March 2005	Final revision of Documents for the NGMS-IMS project

<u>Task 1.2. Characteristics and Requirements of NGMS</u>

This Task maintained the NGMS Characteristics and Requirements in a timely and complete documentation package for the vision and functions of an NGMS.

The NGMS Characteristics and Requirements were documented from both the functional (and where appropriate detailed) Characteristics and Requirements for an NGMS and from the NGMS-IMS project Workpackages meant to provide selected functions. The NGMS Characteristics and Requirements became progressively more detailed description of an NGMS as the results of project Workpackage Tasks were integrated into them. The NGMS Characteristics and Requirements also served as a primary source document in the evaluation and prioritization of on-going and proposed Workpackage Tasks.

Deliverables

The deliverables of this Task provided for annual updates of the NGMS Characteristics and Requirements. These documents were made available on the Internet.

Schedule

April 2003	Task team formation
September 2003	First draft of Task and Workpackage Documents
April 2004	Present draft to membership at the International Workshop
June 2004	Release draft of document for NGMS-IMS project
September 2004	Final review of Workpackage proposal
December 2004	Update Tasks and Workpackage documents

March 2005	Final revision of Documents for the NGMS-IMS project

Task 1.3. NGMS Systems Integration and Modeling Tools

This Task developed and maintained a NGMS systems integration framework and the modeling guidelines for evaluating the integrability of the work products from Workpackage 4, 5 and 6. It considered both horizontal integration (e.g., the things that relate to the floor level) and vertical, integrating functions at the floor, factory, and enterprise levels. The Task team identified inconsistencies and ambiguities among the Workpackages and recommended resolutions. Where appropriate, it recommended interface specifications or other methodologies for ensuring NGMS integrability.

In addition, the Task team took advantage of the strengths and interests of the Regional groups. This Task established the mechanism to integrate the Tasks in Workpackages 4 through 6. The major integration guidelines and models of the Tasks in Workpackage 4, 5 and 6 to assure that the modeling guidelines were based on the object-oriented programming paradigm. One objective of this Task was to ensure that the guidelines were compatible, that their semantics and interfaces were consistent across the Workpackages.

The Task team also developed an NGMS-IMS project acceptance critique that was the basis for international standards. The models developed in the Workpackages 4 through 6 Tasks assured that work units were conducted and negotiations cooperatively for decisions relating to the enterprise's goals and their individual roles in meeting those goals

Deliverables

- A framework for integration of modeling guidelines.
- Evaluations of Workpackage results for integrability.
- A report on integration of guidelines and models

Schedule

April 2003	Task team formation
September 2003	First draft of Task and Workpackage Documents
April 2004	Present draft to membership at the International Workshop
June 2004	Release draft of document for NGMS-IMS project
September 2004	Final review of Workpackage proposal
December 2004	Update Tasks and Workpackage documents
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4.3 Workpackage #4 -- Knowledge Based Information Systems

4.3.1 Scope and Objectives

The goal of this Workpackage was to provide the computing and communications that enable production procedures and technology to be communicated intelligently using the concepts of the Digital Factory as well as multi-media, including virtual reality technology, which can be flexibly adapted to changes in production and operation. The systems developed also perform processing and communications based on computational models and considered interactions among the humans and machines in a work unit. It interfaced the work unit to the manufacturing system and Design Methodology for Intelligent Machines.

The features included:

- Data mining technology were exploited for both Product and Process knowledge
- A multimedia repository of production knowledge and information

- A standard architecture for multimedia knowledge and information exchange
- Utilization of virtual reality technology
- Real-time translation of production-specific concepts and terms among different languages
- Job model based strategies for worldwide negotiations regarding production and production technologies.

4.3.1.1 Tasks, Deliverables, Schedules and Participates

Task 4.1 KPAQ Production Cell

In active during the Phase III project

Task 4.2 A Role-based Dynamic Information Model for a Complex Enterprise Environment

In active during the Phase III project.

Task 4.3 Knowledge Discovery in Product Development and Manufacturing

Manufacturers in the past several decades have had to embrace paradigms that allow them to improve their competitive posture. These paradigms originate from a variety of dimensions that focus on management style, quality, shop floor efficiency, scheduling efficiency, geography, taxation, etc. With the implementation of each of these paradigms the amount of data collected and processed by manufacturers has increased exponentially. For example, many companies have implemented process improvement software to collect their process data; most of the data collected remains unused. These process improvement software systems provide for data collection mechanisms, such as sensors, throughout the manufacturing processes. This has resulted in the accumulation of millions of new records of which 98% is never utilized to make real manufacturing decisions. The new data records collected cannot be utilized as information to improve the process due to the lack of resources. To some extent, this type of phenomenon exists in every manufacturing organization. Therefore, it is time to understand the productive alignment of data collection, database maintenance, and data/information utilization on the manufacturing enterprise to truly understand the manufacturing enterprise of today and the future through both COTS (Commercially off the Shelf) and Custom approaches

An enterprise of the future will be highly computerized and its competitiveness will be expressed with knowledge related metrics. Much tighter integration will be seen across diverse functional areas such as product development, manufacturing, supply chain, the customer, as well as numerous external liaisons. An enterprise of the future is likely to be agile, extended, virtual, model and knowledge-based, and integrated in time and space.

The volume of data generated in manufacturing enterprises is growing at a fast rate. However, the percentage of data that is being actually used is rather small. The emerging concepts in knowledge discovery generalize and extracted knowledge from the local and distributed databases is growing. In addition, new tools that evaluate the utility of the data collected, eliminate obsolete data, and determine useful data to be gathered is being developed.

To build upon the newer concepts of knowledge-based data collection this Task applied the emerging knowledge discovery tools and increased the effectiveness of decision-making in product development and manufacturing within a Digital Factory environment. Many of the knowledge discovery applications today and in the future will employ autonomous systems or embedded knowledge discovery on a chip, thus, leading to the development of intelligent mechatronic systems for the future.

Deliverables

With the focus on industry the Task defined a roadmap of knowledge-based decisions for manufacturing operations from the perspective of both a COTS and Custom approaches.

- Manufacturers were surveyed to gain insight into three basic issues:

  A. The first issue is to define the data and it's characteristics that are captured in the manufacturer's databases.

  B. Secondly, to differentiate data that is being utilized from that which has no current application.

  C. Finally, to identify the personnel/department utilizing the data and if possible the actual data usage.

- A surveyor collected information on each of the selected manufacturers. Examples of the types of information collected included: manufacturer size in terms of sales and employees, the types of products produced, discrete/continuous process, batch production/single piece flow, process layout type, etc. The database from above analyzed the data collected based on the manufacturer's characteristics in order to identify not only a single profile of data requirements for manufacturers, but also a more meaningful profile by realizing the functionality of manufacturer. For example, small manufacturers with less than 50 employees have different data requirements than larger manufacturers with a greater number of employees. Manufacturers that have implemented improvement processes, such as agility, had different benchmarks when being compared to manufacturers that have not implemented these processes.

- A literature search was performed to identify and assess the various knowledge discovery methodologies and techniques. Association discovery, classification, cluster analysis, sequential pattern discovery, temporal modeling, deviation detection, regression, etc. were included in this research. These methodologies and techniques were assessed in terms of their appropriateness to different types of manufacturing databases and then categorized on a broader level to different classification of manufacturers.

- Manufacturers in various classifications that were willing to allow the Task team to apply appropriate knowledge discovery methodologies to specific product development and manufacturing problems were identified for studies.
- A set of metrics were developed that measured the impact of how the modifications to the database and its utilization would impact the problem domain -- each scenario studied utilized a subset of the metrics and results were delivered to the project team.
- The next step was to apply the knowledge discovery methods from the industry studies identified above. The results contained the following stages: human resource identification, problem specification, data prospecting, domain knowledge elicitation, methodology identification, data pre-processing, pattern discovery, knowledge post-processing, and the refinement process. This process required the efforts of the following three individuals: the domain expert, the database expert, and the data-mining expert. This process was applied to a wide range of scenarios including fault diagnosis, process and quality control, process analysis, machine maintenance, product design, scheduling, materials planning control, etc.
- Program activities and associated results were documented.
- Software packages in the format of expert systems were developed that assisted users in utilizing knowledge discovery techniques in the manufacturing environment.

Schedule

- December 2003: Definition of application areas and assessment
- March 2004: Data collection and development knowledge discovery tools
- March 2005: Analysis and implementation of the results

Participants

Leader – Honeywell
Oak Ridge
MEMC
DOE
LG-CNS
Boeing
NASA-JPL
Sandia
US Army
Iowa State University
National University of Ireland
Pusan University
Sungkyunkwan University
Yonsei University

4.4 Workpackage #5 – Information Systems for Effective Global Value Networks

4.4.1 Scope and Objectives

This Workpackage developed the concepts and prototypes for the effective integration and operation of "global village" manufacturing, specifically the extended and virtual value (supplier-producer-customer) networks that exist within the Digital Factory.

4.4.1.1 Tasks, Deliverables, Schedules and Participates

Task 5.1 Reverse Supply Chain Information System

In active during the Phase III project.

Task 5.2 Global Algorithms for Logistics, Analysis, Xecution and Integration

In active during the Phase III project.

Task 5.3 Total Optimization of Manufacturing, Transportation and Logistics System

This Task developed the Digital Factory optimization of manufacturing, transportation and logistics synchronized with customer's demand. The Task extended applicable areas of the NGMS-IMS project Phase I and II research such as Autonomous Decentralized Scheduling System to planning and Supply Chain Management (SCM).

Under the complexity and rapid changeable circumstances of a manufacturing environment; where, the total optimization of the system is rarely obtained, the feasible and satisfying a solution was secured by an autonomous decentralized system composed by self optimized units and their negotiation and co-operation within a Digital Factory.

Deliverables

Using managerial criteria, such as, financial indices a Digital Factory considered was evaluated with the indices being the optimization of the manufacturing Facility. This Task developed the modeling and scheduling methodology focusing on what the autonomous unit should be and what type of information should be prepared and how it should be exchange. A Digital Factory simulator and modeling support system was developed with the aim of practical usage of obtained results. This Digital factory simulator and modeling support system enabled the total optimization of manufacturing, transportation and logistics systems.

Schedule

December 2003:

- Theoretical consideration development.
- Optimization of manufacturing and logistics plan by minimizing cost and lead-time synchronized with estimated product demand.

December 2004

- Development and evaluation of a Digital Factory simulator and consulting support system of production modeling.
- A totally facility optimization model that will consider shipping, manufacturing and logistics plan.

March 2005

- Improvement of Digital Factory simulator by applying it to industry test cases.

- Total optimization of the Digital Factory to include product marketing.

Participants

Leader – LG-CNS
VTT Automation
Fujitsu
VOSTER
Pusan University
Sungkyunkwan University
Yonsei University
Vanderbilt University
Osaka University
Kyoto University

4.5 Workpackage #6 – Reconfigurable Manufacturing Systems

4.5.1 Scope and Objectives

This Workpackage developed a reconfigurable, flexible computer automated Digital Factory manufacturing system, which was able to scale by modular construction to high and low volumes of production. The Tasks within the Workpackage developed the modules of Reconfigurable Manufacturing Systems required to operate a manufacturing enterprise in a way that they are:

- Easy human interpretation of system organization and behavior
- Customization and specialization of sub-system behavior
- Easy system reconfiguration and reuse of sub-system modules
- Efficient solutions to decision problems encountered in:
  - System planning, design and reconfiguration
  - Process and production planning
  - System operation
  - Monitoring and troubleshooting

4.5.1.1 Tasks, Deliverables, Schedules and Participates

Task 6.1 Scaleable Flexible Manufacturing

Today's manufacturing environment is "data rigid" because product and process control data are computed in advance and loaded into machine controllers using proprietary formats before the start of manufacturing. Replacement of this rigid environment with one designed to enable dynamic, intelligent, flexible manufacturing will reduce manufacturing cost.

The Task created a Highly Integrated Product and Process Engineering Environment (HIPPEE) for controlling and simulating manufacturing processes across the supply chain. Each HIPPEE defined as a set of transactions for communicating dynamic product and process control information between design systems, simulation systems and controller systems.

Today, businesses that wish to use flexible manufacturing enterprise systems and intelligent equipment are hindered by the lack of a comprehensive simulation system to describe their manufacturing enterprise. The business and engineering processes that deal with these systems require information at various levels ranging all the way from individual sensors and drives, to abstract representation of capabilities. Further, some information such as equipment status may be required with real-time constraints, while new applications may require access to interface models of the equipment. To be globally successful, the manufacturing enterprise must coordinate, synchronize, and rationalize their production network.

Deliverables

The primary deliverable was a methodology that was built for Discrete Part Machining, PCB Assembly and Paper Goods manufacturing. The methodology Utilized existing standards and protocols where possible to reduce risk:

- Integration of all methodology tools into one framework

- Simulators to support industry sponsor operations
- A Standard Framework for Engineering Design Modeling
- Durability Analysis of PCA
- Collaborative Framework Development

Schedule

December 2003: Development of PC-based Digital Factory Simulator for placement processes based on the information provided by Rockwell.

December 2004: Extension of this Digital Factory Simulator from one machine to multi-machine environment. This supported capacity planning and work order execution.

March 2005: Real-time control of manufacturing cells and a move away from simulation to the implementation on the shop floor controls.

Participants

Leader – Rockwell Collins
Boeing
NASA-JPL
Fujitsu
VOSTER
DOE
Honeywell
Sandia
STEP Tools
iCIMSI
CCAL
IPLnet
ZPA
University of Illinois
Georgia Institute of Technology
Iowa State University
Kyoto University
Osaka University
University of Michigan

Task 6.2 Development and Verification of Control Executives for Manufacturing Cells

A number of factors are driving corporations towards short product life cycles, lower total production volumes and higher-levels of product mixes (because of customization). Thus, there is a crucial need to develop tools and methodologies that assist in the reduction of time and effort spent in planning, specification, designing, validation and deploying manufacturing facilities (typically production cells) for such quickly changing product models. Today, such facilities are developed in a number of sequential steps, with strong decoupling of the mechanical and control/co-ordination issues. This fails to leverage the potential savings possible from the increased level of standardization available in industrial automation, the use of object technologies that allow for better encapsulation and integration of capabilities of sub-systems.

The Task utilized highly integrated XML transactions to control “real” manufacturing production equipment. Widespread dissemination of the new technology required effective demonstrations of its feasibility using real production processes followed by consensus adoption across industry, so that suppliers do not have to adopt different protocols for each customer. Tool vendors were active in the Task to develop the technology, university researchers utilized to fill critical voids, end users to demonstrate feasibility.

The Task team built a comprehensive manufacturing simulation system. The EM Workbench that had been under development for two years at the University of Illinois under the sponsorship of the NGMS IMS project Scalable Flexible Manufacturing team was a key component. The bench implements many levels and services and generates IEC61499 function blocks for the purposes of simulation and control.

Under this Task the EM Workbench further extended to simulate NC operations defined by STEP-NC data to simulate the transactions. In the first three years, the EM Workbench was used to simulate the operation of the three system prototypes.

This Task developed, demonstrated and validated a methodology and engineering process for SFM software within a Digital Factory environment that included the following:

- Successive refinement/decomposition (hierarchically) of a process plan to a control "plan".
- Development of a unified representation of plans/programs at the different levels of decomposition mentioned above.
- Development of software-based plan/program validation techniques.
- Development of an architectural framework of reusable automation object classes consisting of both, the mechanical and electrical/control properties of automation devices such as locators, clamps, servo-controlled positioners etc. along with a core set of supporting services.
- Validation of the framework, including its efficacy, through development and demonstration of a prototype integrated planning, specification, configuration, validation/verification/simulation and control software environment for a specific domain of applications, e.g., robotic welding cells.

Deliverables

The goals of this Task exploited five different aspects of a Digital factory that were addressed as follows:

- **Decomposition of a process plan:** This was being done manually in industrial practice, in an ad hoc manner. Hence the results cannot fruitfully be exploited to formalize and/or automate programming/control tasks at different levels. For this, the Task work formalizing the plan decomposition process module specified its properties and interface, and provided for validation through experimental prototyping. Much of this work depended on the next Task that involves a unified representation scheme for plans and programs at different levels.
- **Unified Representation of Plans/Programs at different Levels:** As industrial automation technologies (specifically, numerical and programmable logic controllers) developed, device programming languages have evolved to make description of tasks in different domains more convenient to the end user. For example, the machining domain uses NC and APT; the robot assembly domain uses a number of vendor specific languages, and metrology users employ DMIS for their representations. Domain-specific task description capabilities are essential to the end user. However, this must not detract from the fact that they can all be translated (interpreted or compiled) into a single unified description that can be used to drive any industrial automation object. A major part of the work in this facet of the Task involved the development/use of an abstract state-machine class as descriptor or a task/program. An actual instance of a task step was configured using the properties of the task domain and the automation object it is meant to control/co-ordinate. The challenges facing such a task involve deciding the proper level of abstraction for such an object so that it was configured to be useful to a substantial set of application domains, yet

to maintain the configuration requirements simple enough to make it easy to configure. Further, a number of services and tools were developed around it to support its easy use. This Task used the adaptation of a number of standards (IEC1131, 61499, etc) and standardization efforts (OMAC, for example) to help in this development.

- **Plan Validation Software:** One big advantage of having a unified representation for tasks at different levels of the process plan decomposition to a control executive is that simulation and validation of the behavior of the system can be carried out simultaneously at multiple levels. In this Task a number aspects were addressed:
    - Visualization and simulation with control logic in the loop
    - State reachability analysis
    - Detection of user-specified inconsistencies

  In general, validation of logic implies enumeration of goals at this time are to be able to assure scalability of such systems to meet the needs of hard real-time discrete parts manufacturing cells, within the size limits of current controllers, including those based on desktop computing technology.

- **Development of automation objects:** With controls increasingly being affected in software, it becomes particularly important to develop software objects that capture both, the controller behavior and the physical behavior of the object. It was possible to develop a library of electro-mechanical objects that were configured to either run simulation models, graphical animations, or run physical devices. This library supported the development of an integrated environment for planning, validation and control.

- **Integrated Simulation and Control Environment:** This allowed for an integrated electro-mechanical planning, design, analysis and control environment. In this Task a small library of objects or object classes and two-position devices like clamps and locators, single servo-controlled positioners and groups of servo-controlled axes (such as positioning tables, etc) were developed. Using this library, a demonstration that used such a system in the design, automated generation and verification/validation of the control logic of a simple cell was developed.

Various studies developed during the execution of digital product and process models having the following broad based advantages for industry were developed:

- Operations planning became 36% faster when a product model was used as the input to CAM systems instead of drawings (Lockheed Martin estimate).
- The number of drawings required to guide the shop floor was reduced by 75% (Raytheon estimate).
- High-speed machinery was deployed 50% more often when it was programmed more safely using full fidelity product models (Cincinnati Machine estimate).

Schedule

- The first and most broad level of technology diffusion achieved by publishing the program specifications as de-facto standards or as formal standards managed by ISO, IEC or an industry consortium formed out of the NGMS IMS program.
- The second level of diffusion achieved by including hardware and software vendors on the Industrial Review Board so that they understand how to implement program interfaces and thereby make the technology available to the supply chain.

- The third level of diffusion achieved by implementing the space, electric, nappy and exploding program pilots to show that the concept is useful and trustworthy.
- The fourth level of diffusion achieved by developing software tools for building and maintaining IEC-61499.

Participants

Leader – Rockwell Automation
Procter & Gamble
Boeing
NASA-JPL
Fujitsu
VOSTER
ICIMSI
CCAL
IPLnet
ZPA
University of Illinois
Georgia Institute of Technology
Iowa State University
Kyoto University
Osaka University
University of Michigan

5. PROJECT ADMINISTRATION

5.1 Project Management Structure

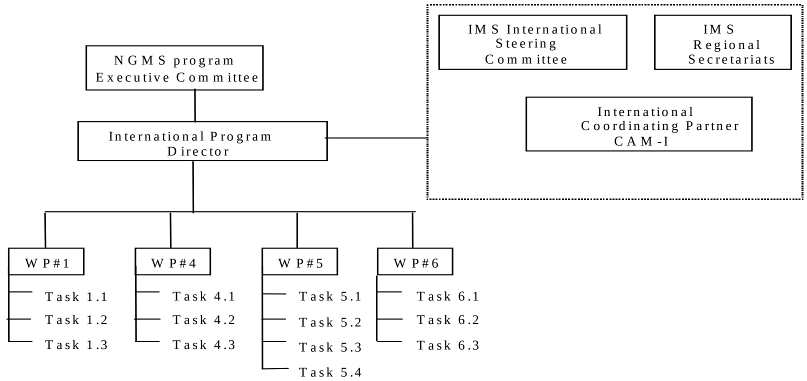

Figure 1: NGMS IMS Project Management Structure

During the NGMS-IMS project Phase I and II efforts the Partners adopted a set of bylaws for the project and elected an Executive Committee. The NGMS-IMS project bylaws and Executive Committee remained enforced for this Phase III project.

With the NGMS-IMS project bylaws from the Phase I and II efforts endorsed the NGMS-IMS project Phase III Executive Committee was elected by the Region members. The Executive Committee was responsible for the setting of policy for the project and for overseeing the administrative and coordination structures of the project through the International Program Director.

The NGMS-IMS project was a balance between the communication and coordination needed for the NGMS-IMS project and the freedom of the Task teams to conduct their R&D work in the most practical and economic manner.

Each Task had an associated Task Plan that defined the following:

- Task Objectives
- Technical Approach
- Milestones and Schedules
- Task Team Organization, Coordination, and Communications

An industry Partner company, by mutual agreement of the Task team, was designated the Task Team Leader and coordinated the actual work of the Task by the members. Academic or vendor partners also worked on Tasks under the supervision of the Task team.

With regard to Task team membership all Regional and Cross Regional Task Teams had membership that was roughly proportional to their Partner region strength. Each regional Tasks team assigned a monitor to participate as appropriate in the primarily Regional Tasks by the Executive Committee.

The NGMS-IMS Phase III project was structured such that it allowed for an annual International Technical Conference, an annual International Technical Workshop and at least three quarterly Region meetings (Each Region). These project meetings allowed for the researchers to share results and develop cross-fertilization of ideas. Each Task team presented their results at the International Technical Conference, International Technical Workshop and their respective Regional meetings. Cross-Regional attendance at Regional meetings was encouraged.

In addition, Task teams organized working meetings to accomplish their objectives.

The NGMS Program Phase III Bylaws governed the project.

5.1.1 Administrative Management

The administrative management of this IMS project was the responsibility of the NGMS-IMS Program Office, as international coordinator partner. The Program Office was responsible for coordinating the inter-regional aspects of the project and was the project's liaison with the International IMS Steering Committee and with the International IMS Secretariat.

The Program Office coordinated the planning, execution, and reporting for the NGMS-IMS Phase III project, coordinated the cross-Regional aspects of the Tasks and Task reviews. The Program office also provided a central repository for the project's work products and documentation, maintain master schedules, and develop materials that were used for outreach to SMEs (Small manufacturing Enterprise) and other potential partners.

The Program Office tracked the technical progress of the project; each Task Team submitted quarterly reports that were collated and distributed to all Partners participating in the Project.

6. Communications Structure

The Consortium for Advanced Manufacturing - International (CAM-I) maintained the Website that was used to provide a communications medium for NGMS-IMS project members. The Website contained general public information describing the NGMS-IMS project, meeting dates and other public information about CAM-I and all of its Programs.

The Website also provided a Private Forum area containing file libraries documents, bulletin boards, meeting minutes, email addresses and other items available only to NGMS-IMS project members via password. This area was used for secure communication among partners. At the conclusion of the project the Website was shut down and all Website information was distributed to the project partners.

7. Technology Transfer and Dissemination

The work completed with this project has moved rapidly into the public domain where it is accessible via the project partners as the dissemination mechanisms.

8. Exploitation

Exploitation of the results of this project occurred in several ways.

- Workpackage 1 was the foundation for the NGMS-IMS Phase III project. The results of Workpackage 1 pervade all other activities within the project.
    - The NGMS Description and certain of the documents, especially those relating to existing or needed standards, from the NGMS Requirements, the NGMS Integration, and the Tools and Model Integration Tasks were delivered to the project partners.
- Workpackage 4, 5 and 6 yielded many models for the NGMS Phase III project. Many related to the factory floor; others to enterprise issues; some linked to the partner’s and finally some related to individual work units; others to virtual enterprises.
- The NGMS-IMS Phase III project Executive Committee members were senior technical managers and leaders from the project Partner

companies. They had the responsibility for exploitation of the results of this project within their companies.

- Consortium Partners, especially those based at universities or technology transfer institutes seeded the SMEs with the project results. Previous experience had shown that the dissemination of R&D results conducted primarily by large companies should be reinterpreted and repackaged if they are to be useful for SMEs.
- Each of the NGMS-IMS Phase III project Regions were committed to work with established technology transfer mechanisms within their Regions.

9. Contributions and Benefits

The NGMS-IMS Phase III project was design to be based on equitable contributions and benefits as viewed by the partner companies. That is, the assumption was that each of the partners made a roughly equal contribution and accordingly gains roughly equal benefits.

Because of the very different funding mechanisms in the Regions, the responsibility for several of the Tasks had been distributed across the Regions so that the Regions were able to pursue funding asynchronously without impeding progress in the other Regions.

9.1 International Distribution of Task Leadership

Certain of the Tasks had a Regional focus; others were cross Regional in nature.

The leadership for the Tasks is distributed as shown in Table 1.

Tasks	**Regional Leadership**	**Tasks**	**Regional Leadership**
Task 1.1	Cross-Regional (Program Office)	**Task 5.2**	In Active
Task 1.2	Cross-Regional (Program Office)	**Task 5.3**	Cross-Regional (Europe Region)
Task 1.3	Cross-Regional (Program Office)	**Task 5.4**	In Active (Japan Region)

Task 4.1	In Active	**Task 6.1**	Cross-Regional (US Region)
Task 4.2	In Active	**Task 6.2**	Cross-Regional (US Region)
Task 4.3	Cross-Regional (US Region)	**Task 6.3**	In Active
Task 5.1	In Active		

Table 1. Regional Focus of the Tasks

9.2 Representative Approaches to Funding

Each IMS Region developed its own approaches to funding its contributions to the project. There was no hope for an internationally agreed upon, coherent, funding pattern that corresponded to a single funding source. All regions participating in this project agreed to self-fund their participation in the NGMS-IMS Phase III project.

9.3 Benefits

It was difficult to quantify the benefits of improved manufacturing technologies and systems for this project. However, each of the NGMS-IMS projects Tasks completed within this project provided benefits for each of the partners. The benefits of participation in IMS differed depending on the nature of the partners, on their competitive posture, and on the infrastructure each had that supported advanced concepts, technologies, and systems.

Table 5 shows the classes of companies and the benefits they derived from the NGMS-IMS project.

Classification of Participation	**Benefits**
Manufacturing companies that are users of advanced technology and systems.	• Lower development and operating costs • Improved competitive capabilitiesThese will result from the proven advanced technologies and systems that are developed internationally, but in a way that are consistent and will permit integration into the companies' next generations of manufacturing systems.

Classification of Participation	**Benefits**
Companies that are vendors of advanced technology and systems.	• Deep knowledge of and access to proven advanced technologies and systems. Lower development costs for products that they can subsequently commercialize. • Access to an international group of key manufacturers as a prototype for participation in international markets.
All companies and research institutes	• Interfaces and data models for integration of advanced technologies and sub-systems. • Standardized practices for preparation of, for example, object-oriented models for all levels of the manufacturing enterprise.
Applied research and technology transfer institutes	• Deep knowledge of the requirements of leading manufacturing enterprises and of proven, directly applicable, advanced technologies and systems. • Access to an international network of thought leaders in manufacturing.
Universities	• Deep knowledge of advanced manufacturing technologies and systems research being conducted internationally. • Exchange of practices for the conduct of university R&D and of manufacturing education.
CAM-I	• Participation in a leading international manufacturing systems R&D activity.

Table 5. Classes of Partners and of Benefits from the NGMS IMS Project.

Beyond the above a few major project benefits are summarized as follows:

- A framework for the integration of advanced manufacturing systems and technologies into next generation manufacturing enterprises. This reduced greatly the costs of integration over the lifetime of the NGMS IMS Project.
- Greatly improved, model based processes and systems that improved industrial competitiveness.

10. Representative Approaches to IPR

10.1 The Cross-Regional Tasks: Workpackage 1, 4, 5 and 6.

In general, each partner contributed equally to Tasks 1.1. 1.2 and 1.3, and had immediate access to the information systems developed to support the NGMS-IMS Phase III project and to the Intellectual Properties generated under the Tasks within the other project Workpackages.

The NGMS-IMS project developed an aggressive plan for presentation and publication of the concepts developed and described in Workpackages. For example, the NGMS-IMS project placed reports on the Websites and did seek international and national venues for their presentation.

10.2 IPR for Workpackages 4, 5 and 6.

The IPR from Workpackage 4, 5 and 6 consisting of modeling tools and techniques, models, and reports documenting their use in systems are owned by the Task participating partners.

Although the general philosophy of the project was one of rapid and open dissemination of proven concepts, techniques, and methodologies, these Workpackages introduces more complicated IPR protection requirements.

Note! The following is a synopsis of the information contained in the Consortia Cooperation Agreement (CCA). Refer to the full CCA For detailed understanding

10.2.1 Background and background rights

It is expected that some Partners will use their BACKGROUND and BACKGROUND RIGHTS in the conduct of Workpackage 4, 5 and 6. It is most likely that this IPR will relate to advance processes, to existing characterizations and models, to existing modeling tools, or to existing data and information delivery systems. Partners will be requested to provide a list of the BACKGROUND and BACKGROUND RIGHTS to all other Partners as soon as it is determined that the BACKGROUND or BACKGROUND RIGHTS will be used in the Project and then to label the BACKGROUND and BACKGROUND RIGHTS accordingly.

Models are instantiations of modeling tools that describe particular machines, cells, factories, or enterprises. Partners will be requested to provide a list of models incorporating their BACKGROUND when the models are disseminated. No models incorporating BACKGROUND will be disseminated publicly without the owning Partner's permission.

The NGMS Project Office will maintain a master list of BACKGROUND and BACKGROUND RIGHTS used in the Project; the master list will be maintained in a section of CAM-I Website that is not publicly accessible.

10.2.2 Foreground

Three classes of FOREGROUND can be expected: tools for modeling and simulation; the models themselves; and the processes modeled and simulated.

Modeling Tools

Modeling tools will be used in Workpackage 4, 5 and 6. It is likely that these tools will be derivatives from existing tools and licensed programming languages and tools. Partners will be requested to provide a list of any tools they regard as FOREGROUND to all other Partners as soon as it is determined that the tools have significant new content and will be used in the Project and then to label the tools as FOREGROUND.

It is likely that the project will want to make information about the tools generally available, although the tools themselves may be deemed to have proprietary value. Partners will be encouraged to commercialize or otherwise make publicly available the tools as a way of promoting the Project's integration approaches and interfaces incorporated in them.

The NGMS Project Office will maintain a master list of modeling tools considered FOREGROUND; the master list will be maintained in a section of CAM-I Website that is not publicly accessible.

Models and Simulations

Especially at the factory and enterprise levels, we can expect the development of new models as FOREGROUND. These models may be used in simulations of novel processes. Partners will be requested to provide a list of FOREGROUND models and simulations when the models and simulations are disseminated and to label them as FOREGROUND.

It is likely that the Project will want to make information about the models and simulations generally available, although some models may be deemed to have proprietary competitive or monetary value. Partners will be encouraged to commercialize or otherwise make publicly available the models as a way of promoting the Project's integration approaches.

The NGMS Program Office will maintain a master list of models and simulations considered FOREGROUND; the master list will be maintained in a section of CAM-I Website that is not publicly accessible.

10.2.3 Inventions

The nature of this project is such that it is unlikely that any inventions will result from this project. In the unlikely event that inventions do result, they will be treated as FOREGROUND.

10.3 NGMS-IMS Project Presentations and Publications

As noted above, the NGMS-IMS project undertook the rapid and aggressive dissemination of advanced systems concepts, processes, and methodologies researched, developed, and proven within the Project.

Publications and presentations by the Project itself do bear the copyright of the NGMS-IMS project. In certain circumstances, copyright will be released to a publication; e.g., as required for publications in IEEE journals.

Associated academicians are able to present and publish research papers. The publications must indicate that they were the result of the NGMS-IMS project.

All project presentation materials were made available to partners and are not publicly accessible.

10.4 Oversight of IPR

Overseeing of IPR is the responsibility of the NGMS-IMS project of the project partners who will determine whether IPR management practices are adequate.

11. CONSORTIUM COMPOSITION

11.1 Regions Involved

The IMS Regions involved with this project were Europe, South Korea, Switzerland, and United States.

11.2 International Coordinating Partner

The International Coordinating Partner, International Program Director was the Consortium for Advanced Manufacturing-International (CAM-I). Contact Information:

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International Program Director
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12. APPENDIX

Additional Tasks either completed or pending for future research:

Tasks identified in the original project proposal as possible work for Phase III and/or beyond Phase III of the NGMS-IMS Project are summarized here for reference and completeness.

Task 4.1 KPAQ Production Cell – pending approval

The acronym KPAQ comes from the Swedish words for Knowledge, Productivity, Working Life and Quality. Increasingly production cells are being developed around products and production systems that require a much higher degree of knowledge than in the past. The inability to recognize this and plan for good utilization of people and equipment has led to many failures in such cells. The concept of the Digital factory in this Task will develop production cells based on very flexible rapid processes with knowledge intensive products and processes. These production cells will be capable of operating and producing at higher productivity by rationalization and integration. Better work life by decentralized information and decisions; increased quality systematization and improved equipment; and improved work as a way of acquiring knowledge.

Early results from the NGMS-IMS project Phase I efforts indicated that integration between production cells and enterprises are not just about the flow of materials, they also must integrate people. Studies have shown that not all technology-led changes succeed, mainly because technological changes are rarely just technological changes.

The joint Japanese/Swedish Task competed as part of the NGMS-IMS project Phase I effort, indicated a number of potential critical success factors for production cells:

- High competency and knowledge among the members of the Task team
- Education in the implementation stage

- Sufficient resources
- Appropriate staffing of the Task team
- All participants are motivated
- Ability to build knowledge
- Involvement of company management
- Integration of both management and shop floor employees
- Company goals, visions and strategies communicated and accepted.
- Sufficient knowledge to be able to evaluate vendor proposals

This NGMS-IMS project Phase II Task will build and exploit the earlier NGMS-IMS project Phase I results and model the production cell within the context of the Digital Factory.

Deliverables

The objective of the research is to obtain high total performance of a production cell by means of cell combination and cell improvement through Digital Factory simulation and then to apply it to an actual industry test case.

Task 4.2 A Role-based Dynamic Information Model for a Complex Enterprise Environment – pending approval

In biology, there is a difference between the history of a single animal, the history of the herd, and the ecological environment in which the herd and the animal find itself. There is a similar difference among the various views of manufacturing product information within any manufacturing enterprise.

One of the major challenges in integrated product realization (IPR) in manufacturing is the ability to use diverse information to optimally complete the required manufacturing tasks. Product data management systems have high model fidelity, significant granularity of information, and sharp engineering precision, but are unable to track the strategic intent or marketing purpose of the product. Such systems focus on the "horizontal" flow of product information, from conception to realization (art-to-part, cradle-to-grave). This can be though of as the genealogy of a particular animal in biology.

Material Resource Planning (MRP) systems concentrate on the "vertical" information needs. MRP systems do not require the high level of fidelity, granularity, or precision that is demanded in IPR. Their problem is not capturing the complexity within a single product, but managing the complexity among a host of products, all of which may demand the limited manufacturing resources. This is why manufacturing scheduling is such a difficulty to both the research and practitioner communities. From biology, this is a definition of the herd and its behavior.

Finally, there are Enterprise Resource Planning (ERP) systems that concentrate on the horizontal business information flow, where customers and their orders are tracked and maintained, financial resources are maintained and enhanced, and humans in the systems are identified and fostered. Such systems require the same level of information precision, fidelity, and granularity as do MRP systems but with the added complication of a mix of functional resource requirements. While existing ERP systems have the advantage of integration of horizontal business data, they have the disadvantages of being expensive, unwieldy, and inflexible. Plus, existing ERP systems do not allow for any but the most limited of supply chain integration. Following the biological example, the ERP system defines the ecological environment that a product finds itself in within the manufacturing enterprise.

The purpose of this Task is to identify and characterize the critical information needs for each of the horizontal and vertical slices of the problem and to determine appropriate integration linkages to assure success when linking the diverse information systems together for creating the integration platform periodic table.

Conceptually this Task draws a great deal from biological and ecological theory. Too much effort has been spent in identifying characteristics of information within an individual dimension of manufacturing, be it horizontal, vertical, or ecological. Too little effort has been expended in evaluating how these three slices or views of manufacturing data and knowledge overlap and can be integrated successfully.

The strategies for this Task are one of divide and conquer. First, the key information required in the horizontal realm will be determined. Next, the horizontal data and knowledge will be investigated. Subsequently, cross-functional knowledge requirements will be extracted. As the final part of the analysis phase overlaps, gaps, and contradictory knowledge will be identified.

With the analysis phase completed, the next phase is to determine degree of optimal overlap among the various demands for data and knowledge. For example, how much engineering design data is actually required in order for an ERP system to function successfully? What aspects of ERP are required during the product design stages of IPR, for example, target costing information.

Deliverables

- Determination of key knowledge required for vertical and horizontal manufacturing knowledge sharing.
- Evaluation of overlaps, gaps and contradictory knowledge.
- Creation of models to determine optimal overlap among vertical and horizontal manufacturing knowledge.

Task 5.1 Reverse Supply Chain Information System – pending approval

Increasingly, manufacturers are being held responsible for the eventual disposal of their products once the items have completed their useful life. It is no longer sufficient to simply toss products in a landfill; manufacturers will be responsible for the reprocessing, and reuse of the parts of the product, or dismantling and disposing of the basic raw materials used in the item.

In order to complete successfully this Task, information systems will need to be created to manage the "reverse supply chain", i.e., the logistics and other systems that will take the product from the customer and return it to the manufacturer. Such systems, while they will have much in common with traditional supply chain information systems, will present unique challenges. Will enterprises create the Digital Factory "virtual reverse supply chain" and, if so, how will they use available tools such as simulation to optimize the supply chain performance? Will there be a need for "reverse CAD" systems, i.e., systems that are designed to support reverse engineering of individual products? What is the novel information challenges that such supply chains present? For example, a reverse supply chain will make the original manufacturer the bottom of the food chain, instead of at the top. This has enormous implication of creation, management, and dissolution of the chain.

The purpose of this Task then is to develop methods and concepts that will allow reverse supply chain information to be seamlessly integrated within a Digital Factory with existing manufacturing systems.

The concept behind this Task is that similar activities that take place today in supply chains must exist in an era where all products must be returned for reuse, reprocessing, or return to raw materials. The question is, then; how much of the existing supply chain knowledge can be used in this "reverse" process? Conceptually, there should be no difficulty and there are firms (such as Fuji and Kodak) and industries (such as aluminum and steel) that have already created such reverse supply chains. However, what will occur when this becomes general practice? What impact will it have on the development of NGME information systems? How will individual product data be maintained and monitored; for example, identifying how many times an individual piece has been reprocesses?

The approach to solving this problem is to begin with those who have already approached the problem, namely single-use camera manufacturers, European automobile manufacturers, and worldwide steel and aluminum manufactures. The objective is to identify key observations that have been gleaned with regard to how such reverse supply chains impact existing manufacturing information systems.

The next step is to identify key suppliers who exist at various tiers of the reverse supply chain and to identify how their information systems are impacted by reverse product flow.

Then, an initial set of reverse supply chain data and knowledge characteristics will be created. Such characteristics will include: identification of unique labeling & shipping information, categorizing the unique attributes of tracking products returning to the OEM, and discovering unique relationships among new product CAD and simulation models and dismantlement product and process design.

Deliverables

- Discovery of key observations by those manufacturing firms and industries that currently employ a reverse supply chain.
- Identification of key characteristics and attributes of reverse supply chain information systems.
- Validation of the results through existing firms and industries.

Task 5.2 Global Algorithms for Logistics, Analysis, Xecution and Integration—completed Phase II

This Task will develop a Digital Factory optimization and simulation model that will minimize the overall fleet operations cost and most effectively distribute material between different manufacturing plants.

Though there have been several simulation models developed to analyze material movement between plants based on certain criteria, literature review suggests that there have not been attempts to develop an optimization model using cross-decomposition methods with the overall objective of reducing total material movement costs. In this Task an optimization model that will minimize the overall material movement costs will be developed. The optimization model will generate a set of feasible solutions. This solution set will in turn be input to the simulation model to accommodate randomness. The output from the simulation model will help the fleet scheduler to visualize the impact of decision variables and also enable a better cost-effective decision to be made.

Even with very few plants, types of trucks and type of material to be distributed, this Task could explode into a very complex problem with several thousand variables. This research will aim at solving this is a mixed-integer programming model using cross-decomposition methods using Bender's decomposition procedures and Lagrangian relaxation. The outcome of this optimization model is a set of feasible solution routes that will minimize the overall fleet cost. This set of feasible solutions will be fed into the simulation model to study the randomness in the system and visualize the best possible solution.

Deliverables

- To minimize overall cost of fleet and distribute material between different manufacturing facilities.
- The optimization model, the simulation model and periodic reports on the progress of this Task.

Task 6.3 Autonomous Distributed Manufacturing and Resource Planning (ADMRP)—completed Phase II

For next generation manufacturing planning, the following will be required:

- Plans of both manufacturing facilities and their operations need to be rapidly and flexibly modified, according to the diversity of customer requirement, shortening of production life cycle and system disturbance.

- To establish an information system architecture which enables flexible and rapid change of the system keeping the functionality and consistency of the system in correspondence with the change of manufacturing manner, goal etc.
- Total planning of manufacturing and its resources for a whole factory to achieve shorter manufacturing lead-time and more cost reduction in the age of global mega-competition.

An autonomous distributed manufacturing and resource planning system will be developed in which each planning function of process sequence, facilities layout, worker distribution and production sequence is respectively defined as an autonomous agent and each agent iteratively cooperates with other agents to achieve optimum planning corresponding to system changes. An agent-based and plug-in oriented information system architecture will also be developed to realize flexibility and agility of the system.

The enhancement of the ADMRP technology will be developed within the concepts of ADMS and BMS that were researched under NGMS-IMS project Phase I activities. The concept of the Digital Factory will play a major role in developing the actual research activities of this Task.

Deliverables

- Prototype of manufacturing and resource planning system
- Report that describes the evaluation results of the system