NISTIR 5978

Initial Manufacturing Exchange Specification (IMES)

IMES Concept Document for Manufacturing Systems Integration

Edited by
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U.S. DEPARTMENT OF COMMERCE
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TECHNOLOGY ADMINISTRATION
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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Arati Prabhakar, Director

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Scope

The scope of this document is the procedures and requirements for developing an Initial Manufacturing Exchange Specification.

Intended Audience

The initial audience for this document includes those System Integration for Manufacturing Applications (SIMA) projects performing applied research and development of solutions satisfying manufacturing systems integration problems.

Document Status

This document is in its first phase as an initial release document. As users of this document gain more experience in applying the concepts and procedures to IMES development, the document will continue to be improved and republished with these improvements.

Introduction

The goal of the U.S. government's High Performance Computing and Communication (HPCC) Program is to accelerate the development of future generations of high performance computers and networks and the use of these resources in the government and throughout the U.S. economy. The HPCC Program was formally established by the High Performance Computing Act of 1991 (Public Law 102-194). The four original components of the HPCC Program were augmented in FY94 with a new component known as Information Infrastructure Technology and Applications (IITA). The IITA component supports research and development efforts that will enable integration of critical information systems and demonstrate feasible solutions to problems of national importance. Twenty-first century manufacturing, i.e., advanced manufacturing processes and products, is one of the challenges to be addressed by IITA activities. Starting in FY97, the components of the HPCC Program are broadened and refocused into Program Component Areas (PCAs). These PCAs build on the foundations established in the previously identified component domains and continue to address the HPCC challenge problems. The PCAs are known as High End Computing and Computation, Large-Scale Networking, High Confidence Systems, Human-Centered Systems, and Human Resources, Education, and Training. The Human Centered Systems (HuCS) PCA - which evolved from the IITA component - performs research and development making the products of computing systems and communication networks more easily accessible and useable to a wide range of user communities. Information interface issues are central to such research and development efforts.

NIST's SIMA Program is the agency's coordinating focus for its HPCC activities addressing the information interface needs of the U.S. manufacturing community. Specifically, the SIMA Program works with U.S. industry to:

- Develop information exchange and interface protocol standard solutions for manufacturing integration problems,
- Establish test mechanisms for validating solutions and implementations, and
- Transfer information technology solutions to manufacturing enterprises.

These efforts will allow manufacturing industries to make use of the National Information Infrastructure (NII) as a mechanism for communicating product and process data among various manufacturing activities such as product/process design, analysis, planning, scheduling, production, and quality control. Manufacturing applications require standard protocols for data exchange (information interfaces) to communicate with each other via NII technologies. The development of information interfaces between the communications infrastructure and manufacturing applications, between different manufacturing applications, and between these applications and their users will improve integration and thereby usability of these systems.

There are three major thrusts for SIMA:

- developing and demonstrating specifications for product and process data exchange between life-cycle applications used in manufacturing industries (mechanical parts, electronic components, and process plants),
- developing tools and supporting conformance, interoperability, and performance testing programs for data exchange standards, and
- developing advanced computing and communications capabilities used for development and dissemination of integration solutions, and providing on-line access of standard reference data and manufacturing information about on-going R&D activities.

The primary output of the SIMA Program will be suites of specifications that meet the interoperability needs for the defined manufacturing life-cycle applications. Some of these specifications will be developed within SIMA, while others will be adopted from existing standards activities underway elsewhere. Key to the success of the suites being accepted by industry is the second aspect: demonstrating that the specifications are solutions to real manufacturing integration problems.

To ensure acceptance, developing these suites of specifications will involve collaborations with a variety of organizations. These collaborations will take on a variety of working relationships that will be defined through cooperative agreements. Examples of these collaborations include:

- Identifying standards development organizations (SDOs) so that an established path from a specification to a standard is supported;
- Leveraging national programs such as the National Industrial Information Infrastructure Protocols (NIIIP), Technology for Enabling Agile Manufacturing (TEAM), Manufacturing Automation and Design Engineering/Rapid Design Exploration and Optimization (MADE/RADEO), and PDES Inc. STEP Pilots so that SIMA project managers can apply their expertise in developing specifications while other programs concentrate on improving the capabilities of the manufacturing life-cycle applications;
- Pursuing collaborations with software vendors to demonstrate how the specifications can be used in actual software products;
- Establishing collaborations with end-users of software products to validate solutions for specific integration problems;
- Pursuing academic collaborators to help advance the technology as needed; and

- Working closely with other government agencies such as Departments of Energy and Defense, National Science Foundation, and National Aeronautical & Space Administration to leverage each other's results.

In addition, a set of companion documents to the IMES will be defined that will allow the results of the IMES process deliverables to be published at key phases of its life-cycle. Both the IMES and its companion documents will have a rigorous review process to ensure the results are of the highest quality and meet the original requirements identified by industry.

The IMES will fill an important void in the manufacturing systems integration process as it exists today. It is clear that companies need to have interoperable manufacturing systems to function in an agile environment. To accomplish such interoperability requires the necessary exchange standards. However, there is a clear recognition in the standards community that the process leading to standards is very slow. The IMES provides a mechanism to develop interim fast-track specifications that can be tested in pilot projects before, or in parallel to, submission to a formal standards development process. As an organization, NIST is positioned as the appropriate organization to develop IMESs because it is viewed as an objective third-party in the area of specification development. Also, and most importantly, NIST is committed to ultimately ensure the IMES enters the formal standards process at the appropriate time.

IMESs provide the means to improve the SIMA Program's ability to meet the needs of the U.S. industry in the area of standards and testing methods by providing a structured approach to the SIMA Program's activities in this arena. This methodology is not completely new, but rather is a mixture of the best techniques presently available to SIMA staff. It is also influenced by the more efficient processes used by standards development organizations and industry programs that support these efforts.

Current IMESs under development within the SIMA Program include:
- Assembly constraints representations for virtual assembly,
- Product data management application interface protocol,
- Manufacturing plant layout representations,
- Manufacturing resource data representations, and
- Shop floor status representations.

Although many types of documentation and supporting efforts are developed during the phases of IMES development, the ultimate product is an exchange specification. Throughout this document you will see "specification" and "IMES" used interchangeably.

The remainder of this document's content is structured as follows:

Chapter 1: provides a general definition for an IMES, describes desired characteristics of an IMES, and gives examples of existing efforts or documents that could be considered portions of an IMES.

Chapter 2: defines the methodology for developing an IMES, outlines the various phases required for IMES development, and identifies appropriate deliverables for each IMES development phase.

Chapter 3: defines the approval process, metrics, and other considerations used to determine completion of IMES deliverables and each IMES development phase.

Chapter 4: provides some initial metrics to assess the success of completed IMESs, and a brief conclusion for this document.

Several appendices follow the main body of the document, covering: a glossary of references, acronyms and terms, bibliography of documents for IMES development, examples of IMES deliverables, and a description of roles and responsibilities of those involved in the IMES process for this document.

Chapter 1: What is an Initial Manufacturing Exchange Specification (IMES)?

An IMES is a proposed solution aimed at improving *interoperability* among independently developed manufacturing software systems. In general, it is the specification of an interface between software systems to be used in supporting a particular manufacturing activity or manufacturing scenario. An IMES is developed through an industry review and consensus process and is accepted by the manufacturing community as an authoritative specification.

There are three types of IMESs that may be developed:

- an interface specification between a human being and a software application;
- an interface specification between two or more software applications; or
- a reference information repository specification.

These are graphically depicted in Figure 1.

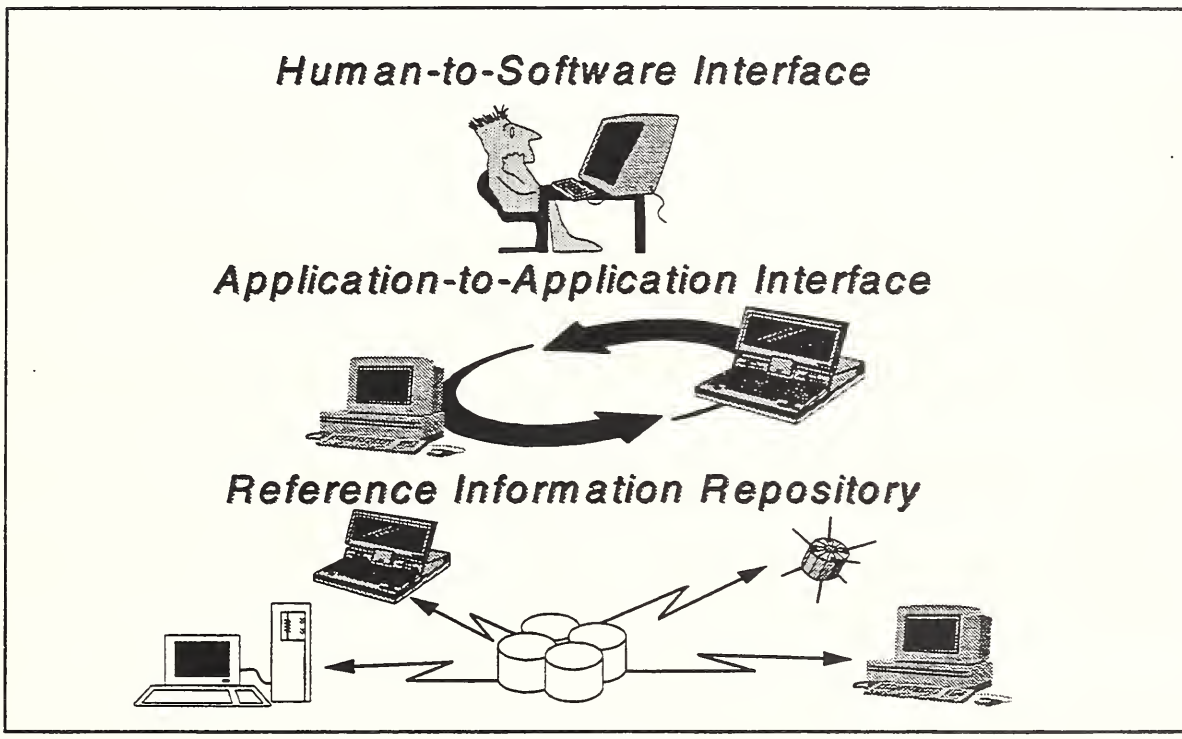

FIGURE 1: THREE TYPES OF IMES

A complete IMES:

- specifies the scope and domain of its applicability, with a supporting manufacturing scenario;
- specifies the interface or information repository;
- identifies its own status, as of publication, in a formal standardization organization;
- states if any implementations are available; and
- references the source documents from which it is derived, or on which it depends.

The following paragraphs provide more detail on these IMES characteristics.

1.1 Scope, Domain, and Manufacturing Scenario

An IMES must specify the scope and domain(s) of the manufacturing software activities it is intended to serve. The scope specifies the manufacturing activities it is designed to serve, and the specific stages in the product life cycle supported. The domain identifies the kind(s) of products being manufactured. An activity to model/define the actual processes used in a particular industry may be a necessary forerunner to developing *any* IMES in that area. Where such a model has been developed, the specification should reference the relevant activities and flows described by that model, and possibly expand on it.

To support the scope and domain specifications, the IMES shall address a particular "example scenario," identifying an actual interface/information requirement derived from a real industrial problem. The proof of the value of the IMES to industry will be the ability to build a prototype to the IMES, using the software applications actually used by the industrial practitioners, and solving the cited problem. Figure 2 shows the data planning model for the application protocol ISO 10303-202, *Application protocol: Associative draughting*; in essence, a high level depiction of ISO 10303-202's scope and domain to meet the particular industrial need [10303-202].

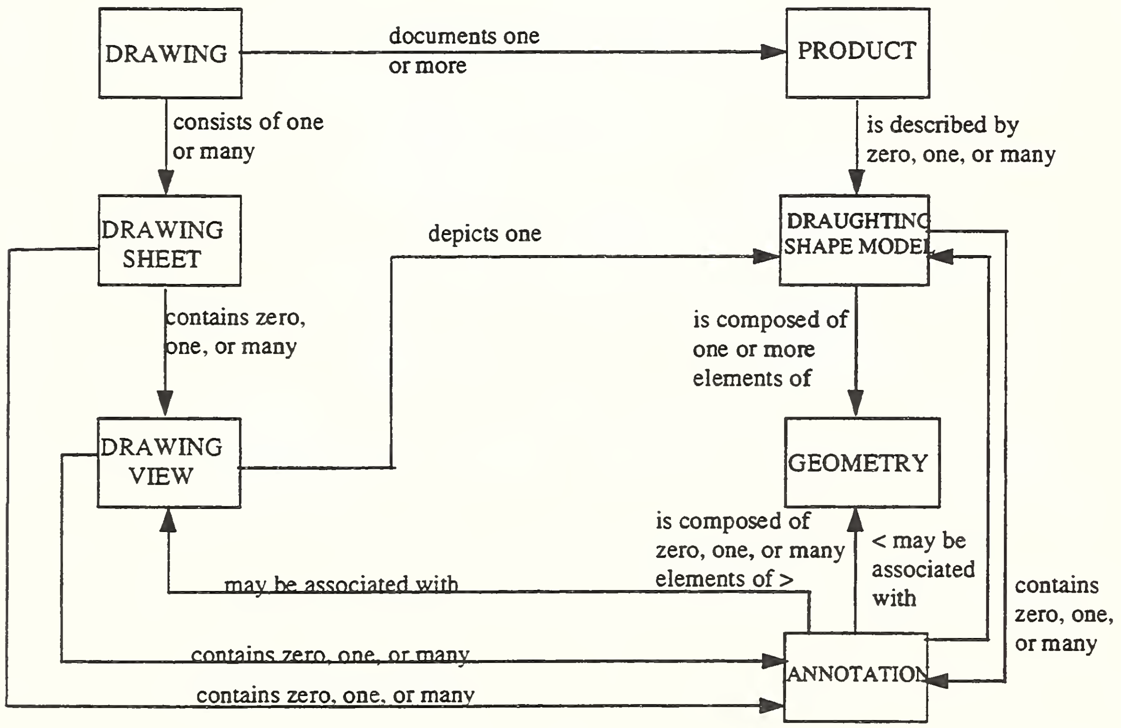

FIGURE 2: SAMPLE HIGH LEVEL DEPICTION OF SCOPE AND DOMAIN

1.2 Specifications

An IMES is a proposed standard solution for a given aspect of manufacturing system integration. The aspect itself is exemplified by the industrial scenario involving integration of two or more manufacturing software systems. Developed from an industry consensus viewpoint, the IMES is accepted by the manufacturing community as an authoritative information specification for the given scenario. An IMES involves several components which define the integration aspect, specifies a definitive solution to the integration problem, and demonstrates the validity of the proposed solution.

An IMES contains a clear description of WHAT information the interface or repository MUST convey, and possibly HOW it is conveyed. The notion "how" may involve several levels of definition, typically by referring to other specifications. Where possible, an IMES should use, incorporate, or refer to existing formal or de facto nonproprietary standards.

All IMESs specify the information which is to be exchanged. The content is usually specified by an information model of all the objects and related information attributes which are covered by the specification. For example, Figure 3, depicts the information requirements in EXPRESS, and the associated graphical representation (EXPRESS-G) for personnel data.

Example of EXPRESS and EXPRESS-G Representation:

```
ENTITY company;
  address : STRING;
  composed_of : SET[1:?] OF department;
END_ENTITY;

ENTITY department;
  location : STRING;
  staff : SET[1:?] OF employee;
END_ENTITY;

ENTITY employee;
 SUPERTYPE OF (ONEOF(salaried, hourly));
  lastname  : STRING;
  firstname : STRING;
  ssn       : INTEGER;
END_ENTITY;
ENTITY salaried;
 SUBTYPE OF (employee);
END_ENTITY;

ENTITY hourly;
 SUBTYPE OF (employee);
  rate : REAL;
END_ENTITY;
```

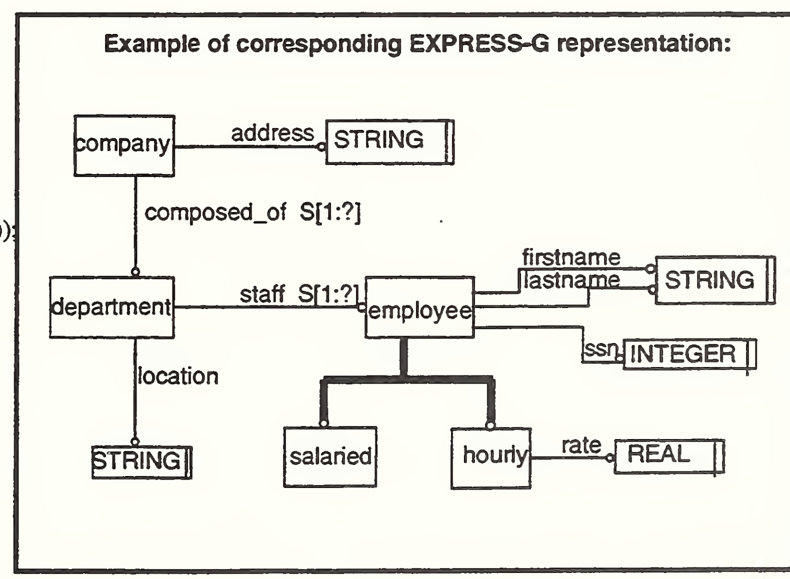

FIGURE 3: SAMPLE EXPRESS AND EXPRESS-G REPRESENTATIONS

When the exchange of information uses a repository, the IMES must define an information model for the content of the exchange. The model may also define the protocol for communication with the repository system. When the exchange of information is directly between two software applications, the IMES must define the protocol for the exchange of information between the two applications.

Where the software packages, or parts of them, are meant to be incorporated in a single executable program, the protocol specification takes the form of an Application Programming Interface (API). A standard API specifies a mapping between a programming language and the features of a particular service, and thereby provides access to that service from applications written in a particular programming language. Such a mapping is said to create a binding between the service and the programming language. A standard API may be part of the standard that specifies the associated programming language, may be part of the standard that specifies the associated service, or may be a separate standard that refers to other standards that define the associated programming language and service [JTC1]. An API defines the subroutine entry-points to be called by the one application and provided by the other, or equivalently, the objects provided by the one and the methods/messages on those objects which can be invoked by the other. (The latter is sometimes termed a class library specification.) For information objects exchanged via the call or invocation, the IMES must specify the parameters. There are two types of parameters: those which have specified data types and possibly specific values, and those which are the identifiers of "opaque" objects whose structure is known only to one or the other side of the exchange. In addition, the IMES must specify additional shared information objects, if any, and rules for the sequencing of calls/invocations.

A practical example of API development is the TEAM API specification. TEAM's API applies to closed loop processing - including module interface programming; command, control and communication; infrastructure and system services; and the scaling of functionality based on selected equipment and desired application. The key objective of defining a TEAM API specification is to enable the design and implementation of an open, modular control architecture [TEAM].

Where the software packages are expected to be stand-alone systems that communicate with one another, the protocol takes the form of a communications protocol, defining messages, requests, and responses; and the specific form of the message on the network. In many cases, such a specification will also identify the standards to be used for conveying the messages, such as a Common Object Request Broker Architecture (CORBA) specification [OMG].

Some direct communication IMESs may involve both communication protocols and APIs. Some IMESs may specify both direct communication and related shared databases or repositories. Some IMESs may mandate the use of other standards which allow the derivation of the complete interchange specification. For example, an IMES may specify a service API using CORBA Interface Description Language (IDL) and require the use of a CORBA Object Request Broker (ORB) implementation to provide the actual communications protocol [OMG]. Similarly, an IMES may contain an EXPRESS [10303-11] model and allow exchange by file using STEP clear text encoding [10303-21] to define the exchange representation, or exchange by a shared database using the STEP *Standard data access interface (SDAI) specification* [10303-22] to define the API.

1.3 Formal Status of the IMES Within Standards Development Organizations

An IMES may reference an existing specification and recommend its use for all or part of a particular integration requirement. If the IMES is or becomes a formal standard, via ISO, ANSI, OMG, or ISA, then the specification shall identify the formal standard development organization.

An IMES may adapt or adopt an existing specification that has no formal standard status, but is the subject of agreements by consortia or national projects or initiatives. In such a case, the IMES project shall ensure that there is a published specification and shall identify that publication.

If the IMES has been proposed as a formal standard to be considered by a standards development organization, or has achieved some status on the way to standardization, the standardization body and status shall be referenced in the IMES.

Finally, a SIMA project may determine that there is no available specification and initiate or participate in an effort to develop an IMES jointly with industrial consortia or standards bodies. An IMES which is purely a draft specification of this type shall indicate this as its formal status. If the draft specification is under consideration by a standards development organization or has achieved some status on the way to standardization, the standardization body and status shall be identified.

1.4 IMES Implementations Available

Since an IMES may adopt an existing specification, there may already be examples of implementations of that IMES. These should be highlighted within the IMES so that current and future users of the specification will know there is supplier support and commercial off-the-shelf solutions available. Where public domain implementations exist, the IMES should identify the procedures one would employ to acquire such implementations. The IMES must state that mention of any implementations does not suggest endorsement of the implementation by NIST or the United States government.

1.5 Resource Documents for an IMES

The IMES shall reference any document which was used as a source for any part of its contents. A reference document could come from any number of sources. It could be a white paper of concepts, published research paper, post-graduate thesis, industrial workshop output, or a preliminary requirement identified by a standards development organization. The common element across all of these types of reference documents is that the idea, once written, lay potentially dormant for want of an organization such as NIST to harness the resources and spark the concept into a practical, implementable specification --- an IMES.

The IMES shall identify any document on which its utility depends. For example, an IMES phrased as an EXPRESS information model for a database to be accessed by SDAI shall identify the relevant STEP parts. Similarly, an IMES phrased in IDL and depending on a CORBA implementation shall identify the relevant OMG standards. All such reference documents should be publicly available and the source specified.

1.6 Examples of IMESs

IMESs may be developed as any one of the three types described above, or a combination of these types, such as an application protocol for STEP. In developing the IMES, the expectation is that the developers will build upon methodologies and document formats that are already in existence and can be merged into a structure that will be appropriate for the SIMA efforts. The following are some good examples that can serve as a basis for obtaining the desired IMES format.

The requirements specification *Modeling of Manufacturing Resource Information* [JUR95], from the NIST Rapid Response Manufacturing (RRM) Intramural Project, is an example of a proposed requirements specification which defines the information model for a reference information repository. The models are formulated in EXPRESS [ISO 10303-11], which allows the schema to be considered for a repository that supports SDAI [10303-22] as the application program interface. Thus the specification defines the information model and the repository schema, and specifies SDAI as the repository access protocol.

The MSI *Control Entity Interface Specification* [WAL93] is an example of a possible IMES for controller and scheduler interfaces using direct communications protocols. The specification defines the scenario and assumptions about the communicating software applications and specifies the messages to be exchanged and the rules for the exchange. The messages are formulated in Asynchronous Syntax Notation (ASN.1) [8824] and are to be encoded by the Basic Encoding Rules [8825].

The STEP *Application protocol: Configuration controlled design* [10303-203] contains several conformance classes. Each class is, in effect, a separate candidate for an IMES to meet a particular industry requirement. In particular, conformance class 6, boundary representation of part solid geometry, specifies the information model for the exchange of part model geometry data between a CAD system and some type of analysis system or manufacturing engineering system. This model is formulated in EXPRESS and the IMES might specify encoding of an exchange file using STEP clear text encoding [10303-21], which is the practice currently supported by CAD systems. Further, conformance class 1, configuration management services specifies the information model for the information managed within product data management systems. Product data management systems typically act as a reference information repository among engineering systems to support part and product version and approval management.

Chapter 2: IMES Development Methodology for SIMA Projects

2.1 Chapter Overview

This chapter defines the methodology for developing an IMES. It outlines the various phases required for IMES development and provides sample deliverables for each project phase. The formats for the deliverables are given in Appendix D. A plan for developing an IMES should describe project activities as outlined below to completely define, justify, validate, demonstrate, and publicize the specific manufacturing scenario and proposed solution.

2.2 Phases of IMES Development

Each IMES project shall include the following project phases as described below. Each phase is a required element of the project. These phases can be considered the main task headings for a generic project plan. Each IMES project should further define the specific tasks under each heading to apply this methodology to the proposed manufacturing scenario or industry need. Additionally, each IMES project should identify the specific deliverables planned for each IMES development phase. Each project must include, at a minimum, the primary deliverable(s) listed below for each development phase. Possible supporting deliverables are also listed below for each phase. SIMA projects should identify any supporting deliverables proposed for inclusion in the project. The following Table 1 summarizes both the primary and supporting deliverables for each phase. The diagram in Figure 4 shows how the IMES phases interact with each other.

DELIVERABLES FOR EACH IMES PHASE		
PHASE	**PRIMARY DELIVERABLE(S)**	**SUPPORTING DELIVERABLE(S)**
Phase 1: Identify/define industry need	• problem statement • manufacturing scenario • project plan	• industry needs survey • workshop proceedings • CRADAs • MOUs • industry support letters
Phase 2: Analyze requirements	• requirements specification for a proposed solution	• industry data • literature review • standards review • application software review • state-of-the-art assessments • workshop proceedings • identification of potential/appropriate standards bodies
Phase 3: Design/develop	• initial strawman IMES	• information model(s) • interface protocol(s) • process model(s)
Phase 4: Validate	• test results	• prototype implementation, • Test environment • Test suites

DELIVERABLES FOR EACH IMES PHASE		
PHASE	**PRIMARY DELIVERABLE(S)**	**SUPPORTING DELIVERABLE(S)**
Phase 5: Build Consensus	• Reviewed/harmonized IMES	• workshop proceedings • industry review • standards development organization review • industry user group interest/actions
Phase 6 Transfer technology	• IMES final report • system demonstrations	• conference presentation • journal articles • WWW homepages • vendor implementations • end-user implementations • commercialization plan • toolkit software release
Phase 7 Initiate standardization	• standards development organization new work item • strawman proposal recognized as committee draft (CD) status	• strawman proposal for standardization • standards development organization new working group • amendment or technical corrigendum to existing standard • implementors' agreement/profile project plan and schedule for developing IMES through standards development organization

TABLE 1: DELIVERABLES FOR EACH IMES PHASE

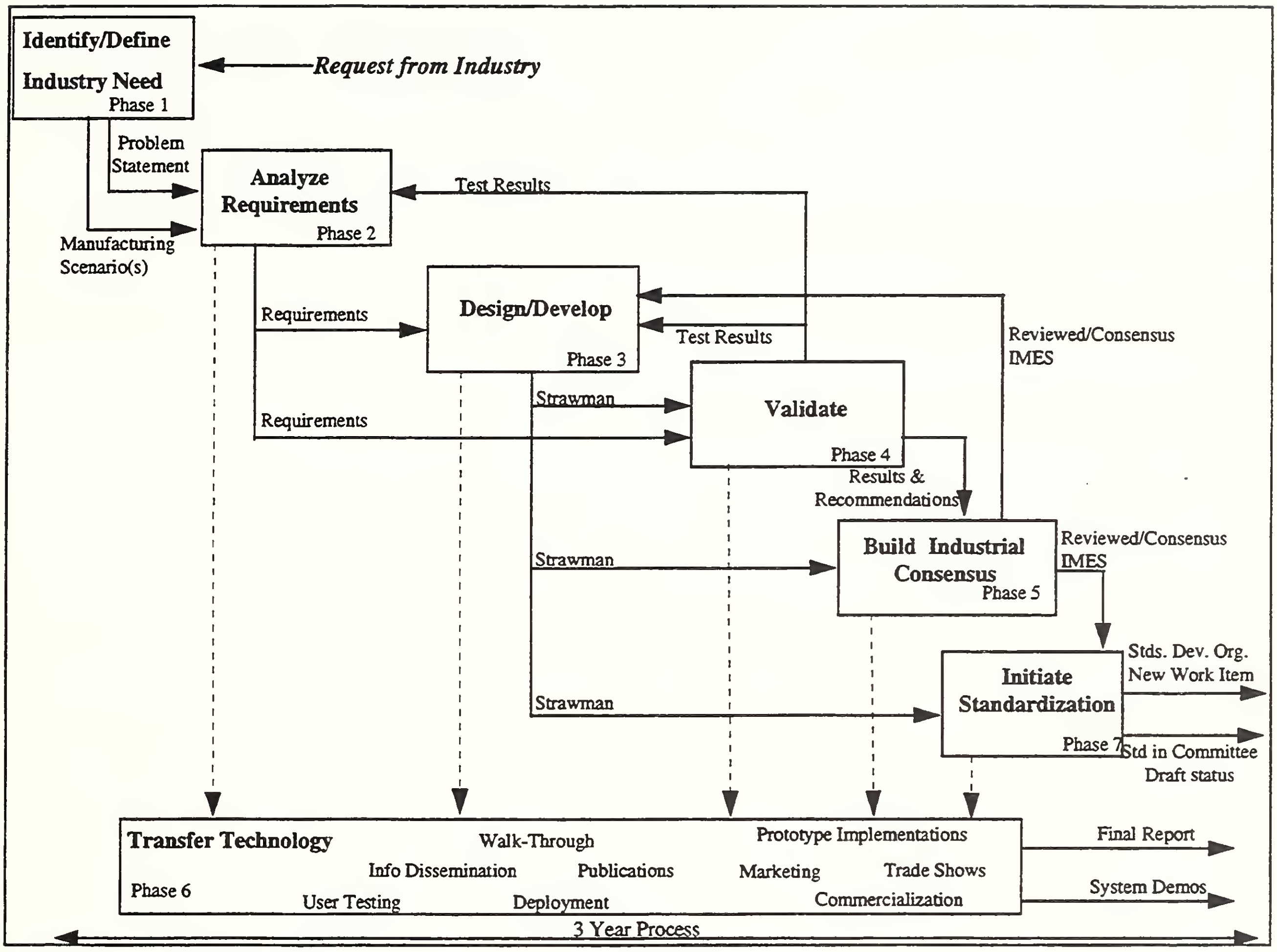

FIGURE 4: IMES PHASES

Phase 1 - Identify/Define Industry Need

The initial activity of IMES development is identifying and documenting an industry need, manufacturing scenario, or problem statement to define the scope and manufacturing domain of the proposed project. This need could be identified in several ways. Typically, however, industrial collaborators should be involved in defining this need. This activity involves the project planning required to initiate an IMES development effort to address the stated manufacturing scenario. This phase shall also define the interface and relationships between the proposed project and the SIMA Reference Architecture, other related projects, and existing standards activities.

Phase 2 - Analyze Requirements

This IMES development phase consists of analyzing the current situation within the manufacturing scenario to understand current capabilities, prior attempts at a solution, and specific needs that must be accommodated in the proposed IMES solution. A requirements specification is the primary desired output from this project phase. Such a specification will enable widespread industry review of the detailed requirements which a solution must satisfy in a form that is understandable by the majority of the target manufacturing community.

Phase 3 - Design/Develop

This IMES development phase consists of the actual design, development, and documentation of the proposed IMES technical solution which satisfies the requirements specified in the previous phase. The solution may consist of a combination of deliverable types, including information model(s), interface protocol(s), or process model(s), as required by the project. The primary output of this phase is the initial version of the strawman proposal for external review.

The content of IMES deliverables will vary depending upon the type of IMES. The following guidance is provided. If the SIMA project is developing:

- an interface between two applications, an IMES shall describe the information model along with the interface protocol used by these applications.
- a series of interfaces between several pairs of applications which all need to work together, then either several information models are needed or a single model which identifies the partitions of information needed by each application must be provided. In addition, a process model shall be provided which describes how all of these applications work together along with the communication or exchange mechanism used by these applications.
- an interface between a human and a software package, an IMES shall describe the information model and the way in which that data is organized and presented to the human.
- a shared reference information repository, then an IMES shall include a information model for that repository and a description of the sharable data collections among applications. Depending on the needs of an application, the minimum meaningful data collection to be accessed might be a cohesive set of highly interrelated information (e.g., a design), or a simple occurrence (e.g., a result of an operation). In addition, a process model should be used to describe which applications create and modify access units in the repository. The mechanism to be used for communicating with the repository shall also be specified.

Phase 4 - Validate

A validation phase is required to ensure the completeness, validity, and usability of the proposed IMES solution. Validation activities may take several forms, including: prototype implementations, detailed walk-throughs with domain experts, or a comparison with known references. A proposed solution with demonstrated prototype implementations and validation test results makes a much stronger case for standardization. When validation activities include industry review or prototype implementations developed by external organizations, this project phase may have some overlap with other IMES development phases (e.g., consensus-building, technology transfer). The documented test results (obviously based upon the prototype implementation, test environment, test suites, or other validation tools) are considered the primary output of this phase.

Phase 5 - Build Consensus

By definition, an IMES is developed from an industry consensus viewpoint. Whereas most IMES development phases require some collaboration or interaction with industrial counterparts, this phase of IMES development requires interaction with a large segment of the target manufacturing community. This interaction can be accomplished through technical workshops, user group meetings, correspondence, or site visits. IMES development projects should endeavor to obtain and accommodate as much input and feedback from industry as possible in the proposed project solution. It is recognized that true consensus may never be reached. This project phase is deemed necessary, however, for positioning and delivering a quality proposed strawman for standardization to an appropriate standards development organization. This phase is differentiated from the actual standardization process to allow and encourage other consensus-building activities without the potential constraints and procedures required by standards organizations. The primary deliverable of this phase is an updated Strawman IMES resulting from the consensus-building activities. In some cases, significant comments and suggestions may indicate the need for the project to iterate back to the IMES Design/develop Phase 3.

Phase 6 - Transfer Technology

One of the primary missions of NIST is to provide technology transfer of NIST research results to industry. The SIMA Program supports this mission. IMES development efforts will include aspects of technology transfer to publicize, market, and transition project activities and results to industry or standards development organizations. Technology transfer should be an ongoing project activity. Various methods of technology transfer can be employed at the various stages of the IMES development effort to supply industry collaborators and the manufacturing community with current information. The primary deliverables for this phase consist of a final report and system demonstrations. The final report should document the activities of the IMES development (what, why, and how), specific results of validation and consensus-building efforts, and lessons learned from the experience of developing the IMES. The final report should also include an implementor's guide to instruct vendors how to implement the IMES and a user's guide to instruct manufacturing users how to use the IMES to meet their requirements.

Phase 7 - Initiate Standardization

Since an IMES is a proposed standard solution to a manufacturing scenario, IMES development efforts must include interaction with appropriate standards development organizations to initiate the formal standardization process. These activities may include attending standards meetings, participating on relevant standards committees, or writing project correspondence to standards development organization conveners. The objective of this phase is to initiate the proposed standards work (either as a new work item or modifications to existing standards/work items) to a point where it will be self-sustaining within the standards development organization. Examples of this stage include: evidence that interest has been generated within a standards committee, a new work item is accepted, committee members are identified, general agreement that modifications to existing work are necessary, or a strawman proposal is registered as a committee draft (CD). It is not expected that SIMA project resources will carry through for the full duration of standardization once the standards work has been sufficiently initiated and has become self-sustaining. Projects should consider that a strawman proposal for standardization must be developed with sufficient consensus and validation prior to submitting the IMES for standardization.

2.3 Project Scheduling Considerations

IMES development phases typically build upon each other, but are not meant to imply total sequential processing. In many cases project phases must be performed in parallel to plan and position project activities effectively. Results of some phases will also indicate the need to iterate back to refine and update a prior phase. For planning purposes, SIMA projects should expect to complete Phases 1 through 7 within a three-year period. It is expected that sufficient results will be obtained to initiate standards work by the end of the third year. It is recognized that actual standardization of the proposed solution could potentially require several years beyond this three year IMES development. These standardization activities are not addressed by the IMES development process.

2.4 IMES Process Example

As mentioned earlier in this document one IMES currently in development is that for manufacturing resource data representations [JUR95]. That effort has been performed in conjunction with the National Center for Manufacturing Science's (NCMS) Rapid Response Manufacturing (RRM) consortium over the past four years. Figure 5, depicts how the activities and results performed in that effort map into the IMES phases. For phase 1 needs surveys and state-of-the-art assessments led to the definition of an industry need and a plan for addressing that need. In phase 2 a detailed specification of requirements was published. In phase 3 an information model satisfying the requirements specification was produced. In phase 4 a test environment for prototype implementations was developed. In phase 5 industry reviews of the specifications were performed. In phase 7 presentations of the work to relevant standards bodies was performed and a "home" for the work was identified. It is noteworthy that technology transfer (phase 6) is performed throughout the process and not just as a single, sequential aspect of the effort.

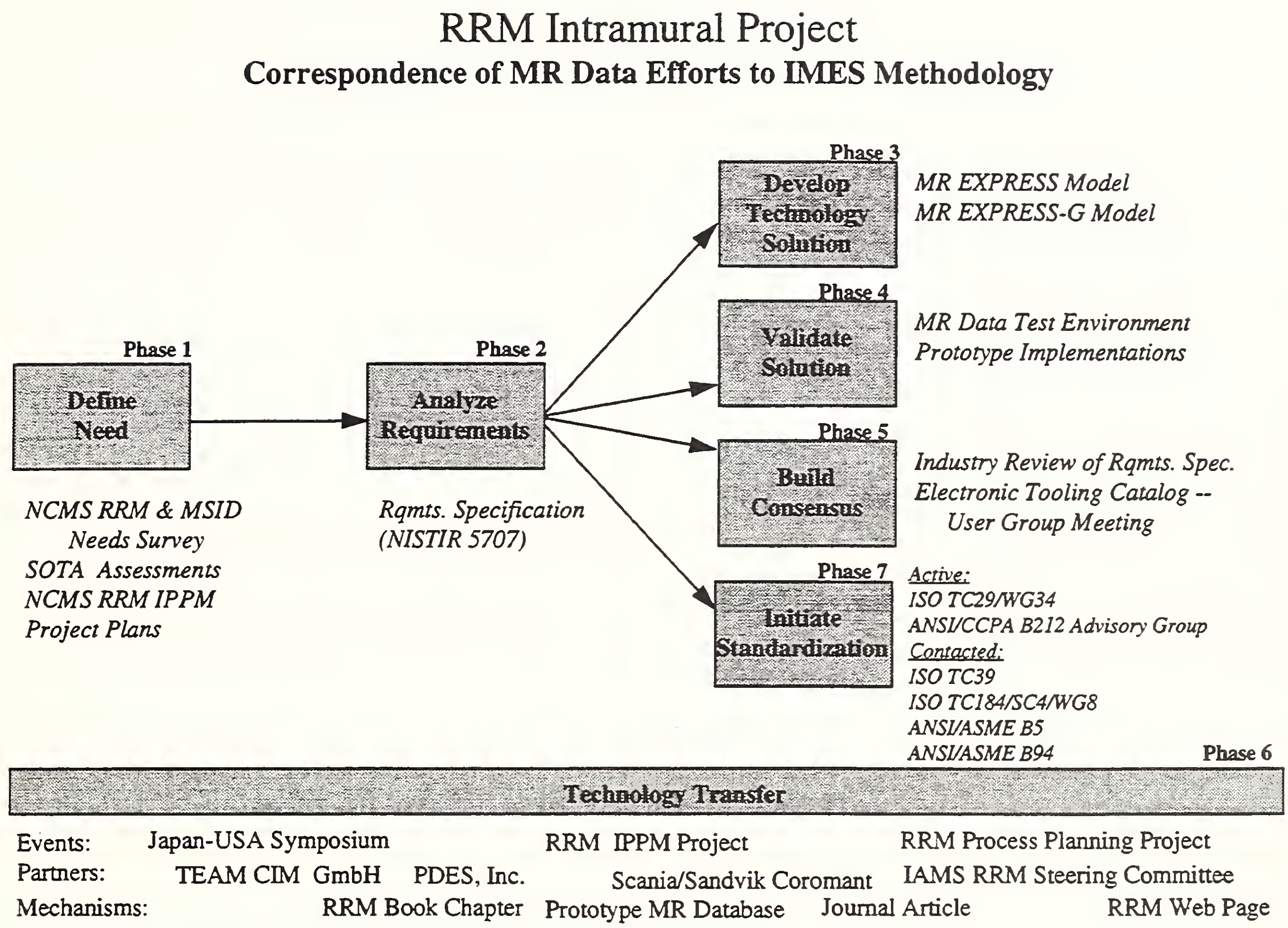

FIGURE 5: MANUFACTURING RESOURCE IMES EXAMPLE

Chapter 3: SIMA Approval Process for Completion of IMES Development Phases

3.1 Chapter Overview

This chapter defines the characteristics of IMES results that are expected to be produced within a SIMA project and the approval process for completing each phase of the IMES development project. This section will outline the overall characteristics and the requirements for completing each of the various phases which include:

- Identifying industry need;
- Analyzing requirements;
- Designing/developing;
- Validating;
- Building consensus;
- Transferring technology; and
- Initiating standardization.

3.2 Content and Characteristics of IMES Deliverables

Completing each phase requires completing the primary IMES deliverables and possibly one or more supporting deliverables depending on the nature of the project. The elements within a document will vary based on the type of interface defined.

The IMES project deliverables shall have the following characteristics:

- **Appropriate scope**: Document a scope that is well-defined, with clear bounds and purpose. State the context of each deliverable with respect to the previously defined scope and scenario.

- **Required reference information**: Specify references to any other interfaces, specifications, and definitions that are required to interpret the IMES deliverable and the publication date of the reference in an introductory section of the IMES. Avoid replicating existing work already accomplished.

- **Consistent use of methods**: Where sufficient, use well-defined and industry-accepted specification methods. All IMES deliverables shall be consistent in their use of any information and process modeling method employed in the work. Usage guidelines exist for many of the methods which are candidates for selection by SIMA projects.

- **Compatible interfaces:** Reuse existing data and functional models wherever possible to provide a mechanism for interoperable applications. Interim deliverables should be accessible to facilitate developing compatible interfaces among IMES deliverables. Deliverables should have a modular design based on functional capability. Common requirements among IMESs should be satisfied by a common interface.

- **Traceability**: Each IMES development phase shall contain elements which are traceable to input from a prior phase. For example, a information model from the Development Phase 3 shall contain elements which are traceable to the requirements identified in Phase 2.

3.3 Approval Process for Completing a Phase

Since there is more than one allowable entry point, due to the opportunity to leverage existing work, this process describes only what is necessary to say that a given phase is complete. Phases and deliverables from each phase are described in section 2.2 of this document.

Phase 1 - Identify/Define Industry Need

In this phase an IMES planning proposal is submitted to the sponsoring laboratory management for review and approval. The mechanism used for laboratory approval is reviewed/approved by the SIMA Program Office. This should be a brief document that identifies the industry need, describes the context of the document in the overall SIMA architecture [BAR96], and documents the envisioned benefits of the work. The kind of IMES deliverable to be produced should also be identified. It should describe the industrial context which should include identifying the industry sector that is the target audience, a manufacturing scenario in which the IMES would operate, the types of products and applications which the IMES is applicable to, the types of companies needed to participate, and any beneficial strategic alliances with consortia or associations.

Completing this phase requires:

- Approval of the IMES project proposal, including preliminary statement on the scope and relationships to other projects, by the SIMA Program Office;
- Approval by the SIMA Program Office of the proposed mechanism to be used for the external review by industry; and
- Review and approval by the sponsoring laboratory management.

Phase 2 - Analyze Requirements

Completing this phase requires that the deliverables have a clear and consistent statement of requirements that are associated with explicit functions within the IMES scope. The requirements specification should document the results of the analysis and should include an analysis of representative implementations or solutions, relevant standards, and priorities. Alliances with consortia or technical/trade associations can be an efficient means of collecting and identifying industry requirements and priorities. The method for documenting requirements and setting priorities should be identified. Identifying the applicability to the previously defined manufacturing scenario should be stated, when appropriate, to provide a context for reviewers.

Completing this phase requires:

- Agreement by the project team, related project leaders and industry collaborators, as documented by minutes or other informal means, that the requirements specification is ready for broader review;
- Identification and SIMA Program Office approval of the mechanism to be used for obtaining broader industry review of the IMES;
- Evidence of efforts to obtain industry feedback are documented. The results, means and breadth of activities should be stated which include: list of issues, list of active industry reviewers, and list of workshops conducted with industry representatives; and
- Agreement by the project leader and SIMA Program Office that the selected requirements method has been consistently applied.

Phase 3 - Design/Develop

Since the solution may consist of multiple deliverable types, including information model(s), interface protocol(s), and/or process model(s), as required by the project, each type of deliverable may require different assessment criteria. The project should document how the requirements are satisfied by the specification (the primary deliverable of this phase). Specific aspects of any interface specifications which potentially interoperate or otherwise impact other current or planned SIMA projects should be reviewed by the SIMA Program Office. Some industry involvement at this phase is expected. There may be direct collaboration, but there must be evidence of one or more industry reviews. The project leader is responsible for identifying which aspects the SIMA Program Office and other SIMA project leaders should review. The SIMA Program Office is assigned the responsibility to review any deliverables and determine if they are consistent with the stated scope and requirements, then verify that the specifications are consistent with the deliverables in the project plan.

Completing this phase requires:

- A statement of collaborator commitment and level of participation is provided;
- An industry reviewer judges the document to be adequate for the approved scope;
- A list of reviews and associated industry reviewers is provided to the SIMA Program Office;
- The specification fits into, and is consistent with, the SIMA architecture;
- The specification is consistent with the approved scope and demonstrates traceability to requirements;
- The SIMA technical reviewer agrees that the document consistently uses selected methods; and
- a WERB-approved draft IMES.

Phase 4 - Validate

A walk-through with domain experts on how the specification would be applied to the usage scenario is a typical initial validation activity. The example input and output data identified during requirements definition and development phases should be used for building test cases. These test cases should capture typical operations which access manufacturing data to more concretely validate the data or process models. Test cases should be defined which document coverage of the functional requirements and representation specifications. Any guidance on the approach to be used should be referenced and followed. It is not generally feasible to validate all aspects of a specification so it is important to set priorities and document which aspects were validated. An actual system prototype with more than one vendor or a reference implementation should also be undertaken to provide more persuasive results where appropriate. The list of products reviewed or used and vendor representatives participating in the validation should be included in the documentation.

Completing this phase requires:

- A test report which describes the validation activities, approach, environment, usage scenarios, and test results, including a statement of what was covered by validation (100% is not practical) and the rationale for what was included or excluded in the validation;
- Test cases are identified and documented for the industry scenario defined in Phase 1; test cases should pass any quality checks appropriate for the interface specification; and
- Documentation indicating that industry reviewers judge validation coverage to be adequate.

Phase 5 - Build Consensus

Completing this phase requires broad review by members of the target industry and vendor community. The goals are acceptance by an identified user community and affirmative results from the call for participation based on the circulation of the IMES specification. The identified user community could be an informal or accredited standards development organization, a consortium, trade association or any alliance of companies that forms to meet a common objective. The objective of this Phase is to gain agreement to pilot and ultimately use the IMES as modified by a consensus process, and to obtain buy-in from the vendor community to build products to the specification.

Completing this phase requires:

- Identification of the method used to obtain consensus by the sponsoring organization;
- Evidence that consensus was achieved to use the IMES specification as the strawman for standardization as defined by the consortium or accredited standards organization;
- Commitment from a user community to promote use of the specification; and
- Pilot initiation and vendor commitment to product development.

Phase 6 - Transfer Technology

The ultimate proof of technology transfer is evidence that commercial implementations of the specification are being used in production applications. Outputs from this phase can include: system demonstrations, conference presentations, journal articles, releases of reference software implementations, or WWW project description pages. The project leader in conjunction with the approval of SIMA Program Office needs to determine how much of the specification is suitable for formal standardization and anticipate how much of the standards process will require active participation by the project. The factors involved in determining this participation should be documented in a final report.

Completing this phase requires:

- Final report judged adequate by SIMA Program Office; and
- System demonstration.

Phase 7 - Initiate Standardization

This phase will overlap with consensus building when a viable standards activity exists which covers the scope of the IMES. If such an activity does not exist, this phase will include: identifying a target standards development organization, the proposal of a new work item to a standards activity, the acceptance of this new work item by an informal or accredited standards body and affirmative results from the call for participation, and the circulation of the IMES as the strawman for standardization. The standards development procedures become the principal approval process. The rules on the release and progression of the proposed draft standard will be followed. The standards process places additional documentation requirements on the development team, such as circulating issues and resolutions. The project leader needs to track progress, assess the participation in the standards project, and determine when active participation in the standards process can be terminated.

Completing this phase requires:

- Successful balloting of a new work item proposal, and identifying the requirements for participation;
- A plan specifying necessary requirements to complete the standardization of the IMES through a standards development organization.

The following Table 2 provides a summary of the phase completion requirements and the responsible authority for ensuring each aspect of completion has been met.

PHASE COMPLETION REQUIREMENTS		
PHASE	**PHASE COMPLETION REQUIREMENTS**	**REVIEWER**
1	• Approval of the IMES project proposal, including preliminary statement on the scope and relationships to other projects;	SIMA Program Office
	• Approval of the mechanism used for external review.	SIMA Program Office
	• Review and approval by the sponsoring laboratory management	Laboratory Management
2	• The requirements specification is ready for broader review, as documented by minutes or other informal means;	Agreement by the Project Team, related project leaders and industry collaborators
	• Evidence of efforts to obtain industry feedback are documented. The results, means and breadth of activities should be stated which include: list of issues, list of active industry reviewers, and list of workshops conducted with industry representatives;	SIMA Program Office assesses alliances with industry consortia or trade associations
	• The selected requirements method has been consistently applied by project leader.	Agreement by project leader and SIMA Program Office
	• Identification and approval of the mechanism to be used for obtaining broader industry review of IMES.	SIMA Program Office
3	• A statement of collaborator commitment and level of participation is provided;	SIMA Program Office
	• Document is judged to be adequate for the approved scope;	Industry reviewer
	• A list of reviews and industry reviewers is provided to the SIMA Program Office;	SIMA Program Office
	• The specification fits into and is consistent with the SIMA architecture;	SIMA Program Office
	• The specification is consistent with approved scope and it demonstrates traceability to requirements;	SIMA Program Office
	• The SIMA Program Office agrees that the document consistently uses selected methods;	SIMA Program Office
	• WERB approved draft IMES.	NIST WERB authorities

4	• A test report which describes the validation activities, approach, environment, usage scenarios, and test results, including a statement of what was covered by validation (100% is not practical) and the rational for what was included or excluded in the validation; • Test cases are identified and documented for the industry scenario defined in Phase 1; test cases should pass any quality checks appropriate for the interface specification; • Judge validation coverage to be adequate.	SIMA Program Office SIMA Program Office Industry reviewers
5	• Identification of the method used to obtain consensus by the sponsoring organization; • Evidence that consensus was achieved to use the IMES specification as the strawman for standardization as defined by the consortia or accredited standards body; • Commitment from a user community to promote use of the specification; • Pilot initiation and vendor commitment to product development.	SIMA Program Office SIMA Program Office SIMA Program Office SIMA Program Office
6	• Final report judged adequate; • System demonstration.	SIMA Program Office SIMA Program Office
7	• Successful ballot of a new work item proposal, including requirements for participation; • Plan to support completion of the standard.	Standards Development Organization Standards Development Organization

TABLE 2: PHASE COMPLETION REQUIREMENTS

Chapter 4: Conclusion and Document Status

In order to determine the success of the IMES concept and of published IMESs, the SIMA Program Office will conduct an annual assessment. Basic metrics will be applied to each IMES for three (3) years after its publication. Metrics for assessment may include:

- is the IMES actively progressing through a standards development organization?
- are implementations of the IMES being built by commercial enterprise for production use?
- are users applying IMES implementations to meet their requirements?
- after three (3) years of the IMES's publication, has it been deployed in some fashion by industry?

This document has attempted to capture initial thoughts regarding the definition of an IMES, the development process for creating an IMES, and approval procedures for IMES development projects. The procedures described in this document are considered initial concepts and will change with time as the SIMA project leaders gain further experience with IMES development. As IMES development projects are initiated and proceed through the various development phases, it is expected that both modifications and additions to this document will be identified. As such, this concept document should be considered a living document. Readers should feel free to provide written comments to the following for consideration in future updates to this information:

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Appendix A: References

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[10303-1] ISO 10303-1:1004, Industrial Automation Systems and Integration, Industrial Data and Global Languages, Overview and fundamental principles.

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[10303-21] ISO 10303-21: 1994, Industrial Automation Systems and Integration, Industrial Data and Global Languages, Implementation method: Clear text encoding of the exchange structure.

[10303-22] ISO DIS 10303-22, Industrial Automation Systems and Integration, Industrial Data and Global Languages, Implementation method: Standard data access interface specification.

[10303-202] ISO 10303-202: 1996, Industrial Automation Systems and Integration, Industrial Data and Global Languages, Application protocol: Associative draughting.

[10303-203] ISO 10303-203:1994, Industrial Automation Systems and Integration, Industrial Data and Global Languages, Application protocol: Configuration controlled design.

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[WAL93] Sara Wallace, M. K. Senehi, Edward Barkmeyer, Steven Ray and Evan Wallace: Manufacturing Systems Integration Control Entity Interface Specification, NISTIR 5272, National Institute of Standards and Technology, Gaithersburg, MD, 1993.

Appendix B: Glossary of Acronyms and Terms

Acronyms

ANSI -	American National Standards Institute
AP -	Application Protocol
API -	Application Programming Interface
ARM -	Application Reference Model
ASN.1 -	Asynchronous Syntax Notation
CAD -	Computer-Aided Design
CD -	Committee Draft
CORBA -	Common Object Request Broker Architecture
CRADA -	Cooperative Research and Development Agreement
DIS -	Draft International Standard
HPCC -	High Performance Computing and Communications
IDL -	Interface Description Language
IEC -	International Electrotechnical Commission
IITA -	Information Infrastructure Technology Applications
IMES -	Initial Manufacturing Exchange Specification
ISA -	Instrument Society of America
ISO -	International Organization for Standardization
MADE -	Manufacturing Automation and Design Engineering
MOU -	Memorandum of Understanding
MSI -	Manufacturing Systems Integration
MSID -	Manufacturing Systems Integration Division
NII -	National Information Infrastructure
NIIIP -	National Industrial Information Infrastructure Protocols

NIST - National Institute of Standards and Technology

OMG - Object Management Group

ORB - Object Request Broker

PCA - Program Component Areas

PDM - Product Data Manager

RADEO - Rapid Design Exploration and Optimization

RRM - Rapid Response Manufacturing

SDAI - Standard Data Access Interface (ISO DIS 10303-22)

SDO - Standards Development Organization

SIMA - Systems Integration for Manufacturing Applications

SOLIS - SC4 On-Line Information Service

STEP - Standard for the Exchange of Product model data (informal name of ISO 10303, *Industrial automation systems and integration - Product data representation and exchange)*

TEAM - Technology for Enabling Agile Manufacturing

WWW - World Wide Web

Terms

Application Programming Interface – a set of procedures, usually written in some standard programming language, callable from an external user-generated program. Such procedures may provide access to some of the functions of the application system, or provide access to the data it maintains, or both. [BAR95]

Application Protocol - a part of this International Standard [ISO 10303] that specifies an application interpreted model satisfying the scope and information requirements for a specific application. [10303-1]

Class Library – a kind of API specification in which the interface is specified in terms of information objects and the operations on them. Class libraries are language-specific and the term often implies a C++ implementation.

Common Object Request Broker Architecture – the canonical distributed systems architecture proposed by OMG.

High Performance Computing and Communications - A federal government initiative whose goal is to accelerate the development of future generations of high performance computers and networks and the use of these resources in the Federal government and throughout the American economy. The HPCC program fully supports and is closely coordinated with the effort to accelerate the development and deployment of the National Information Infrastructure (NII). The Program and its participating agencies help provide the basic research and technological development to support NII implementations.

Interface Description Language – a language for specifying the API to an application software package. IDLs are designed to avoid the idiosyncrasies of particular programming languages and tools are then developed to provide the mapping of an API phrased in IDL into subroutines compatible with a user's target programming language. The subroutines employ some service/protocol associated with the IDL to access the software package. Two IDLs are in common use: the CORBA IDL, whose tools use an Object Request Broker, and the Distributed Communications Environment (DCE) IDL, whose tools use (unix) Remote Procedure Calls (RPC).

Information Model – a formal identification of the objects in an interchange, their interrelationships, and the information units which describe those objects. It may or may not include identification of the operations on those objects.

Initial Manufacturing Exchange Specification - A clear written description of WHAT information the interface or repository MUST convey, and possibly HOW it is conveyed.

Interface Protocol – a formal description of the messages exchanged between two communicating entities and the rules for the exchange of those messages.

Interoperability - the successful exchange and use of information between two or more dissimilar systems [KEM92].

Process Model – a formal description of the behavior of a system, including the activities it performs and the required states or events which will cause it to perform them. (A programming language is a process-modeling language, but at a very fine degree of detail.)

Product Data Manager - an information system whose function is to maintain collections of data and to provide them to other information systems (such as application packages) on request. The rules for modification of the information in the repository (who/when) define behavioral characteristics that typify certain subtypes of repository. We distinguish between reference repositories, which most customers cannot modify, and interface repositories, which are routinely read and modified by all participants to the interface.

Protocol – the rules for communicating: see Interface Protocol and Application Protocol terms.

Appendix C: Related Documents

Methods Documents

Several methods documents for preparing STEP parts have been approved as SC4 Standing Documents for use within the ISO TC 184/SC4 community. The current titles are listed here, and they are available on-line from SC4 On-Line Information Service (SOLIS) under the common directory path: SC4/how to/methods/. The current SC4 N#s are also designated; however, SIMA project managers are encouraged to ensure the most recent version is applied when undertaking IMES development. Although these methods documents are currently specific to STEP, SIMA project managers may also find them useful for other IMES development as well.

- SC4 N 432 *Supplementary directives for the drafting and presentation of ISO 10303*
- SC4 N 433 *Guidelines for the development and approval of STEP application protocols*
- SC4 N 434 *Guidelines for the development of abstract test suites*
- SC4 N 435 *Guidelines for AIM development*
- SC4 N 436 *Guidelines for the development of mapping tables*
- SC4 N 437 *Guidelines for AIC development*

Standards Development Organization Directives and Guidelines

ISO Directives and other Publications.

The following are the most current versions of Parts 1 through 3 of the ISO Directives:

- ISO Directives Part 1, *Procedures for the technical work* , June 1995.
- ISO Directives Part 2, *Methodology for the development of International Standards*, 1989.
- ISO Directives Part 3, *Drafting and presentation of International Standards*, 1989.

These directives, other ISO style guides and publications, and published SC4 international standards are available through ISO Central Secretariat. Purchasing information can be found on the "Welcome to ISO Online" world wide web home page:

http://www.iso.ch/welcome.html

Appendix D: Examples for Deliverables

This appendix consists of references to existing documents or sources of information that illustrate examples of specific types of IMES deliverables. These examples are grouped by IMES phases and the specific type of deliverable (primary and secondary) is identified for each example as appropriate to that IMES phase.

Please note: The editor of this document recognizes that this appendix does not include examples for all deliverables. It is expected that future editions of this document will be able to reflect developmental growth of the IMES concepts and further clarify through future examples listed here.

Phase 1 - Identify/Define Industry Need

Type: Problem Statement

- Example: Jurrens, Kevin K., Mary Elizabeth A. Algeo, and Jim Fowler, "Beyond Product Design Data: Data Standards for Manufacturing Resources," to be published as Chapter 5 in Rapid Response Manufacturing: Contemporary Methodologies, Tools, and Techniques, Dr. Jian Dong (editor), Chapman and Hall, 1996.
- Example: Rosenfeld, David A., Shantanu Dhar, Procedure for Product Data Exchange Using STEP Developed in the AutoSTEP Pilot, NISTIR 5833, National Institute of Standards and Technology, April 1996.

Type: Manufacturing Scenario

- Example: Jurrens, Kevin K., Mary Elizabeth A. Algeo, and Jim Fowler, "Beyond Product Design Data: Data Standards for Manufacturing Resources," to be published as Chapter 5 in Rapid Response Manufacturing: Contemporary Methodologies, Tools, and Techniques, Dr. Jian Dong (editor), Chapman and Hall, 1996.

Type: Project Plan

- Example: Jurrens, Kevin K., and Mark E. Luce, Project Plan for the Rapid Response Manufacturing (RRM) Intramural Project, NISTIR 5174, National Institute of Standards and Technology, February 1993.

Type: Industry Needs Surveys

- Example: Barkmeyer, Edward J., Theodore H. Hopp, Michael J. Pratt, and Gaylen R. Rinaudot, editors, Background Study - Requisite Elements, Rationale, and Technology Overview for the Systems Integration for Manufacturing Applications (SIMA) Program, NISTIR 5662, National Institute of Standards and Technology, September 1995.

Type: Workshop Proceedings

- Example: Ray, Steven R., editor, Proceedings of the 1993 Industrial Process Planning Workshop, June 17-18, 1993, Gaithersburg, MD, NISTIR 5284, National Institute of Standards and Technology, October 1993.

Type: CRADAs

In general, CRADA content is proprietary in nature. Because of this, it is not appropriate to cite particular CRADAs in exemplar form. The technical representatives from NIST's Technology Services Office identified for each NIST operating unit. These representatives can assist you for your particular needs.

Type: MOUs

- [Industrial] Example: Industrial Memorandum of Common Understanding on the Use of STEP (ISO 10303). The aerospace signature parties represented on this MOU are Rolls-Royce, Pratt & Whitney, General Electric, Boeing Commercial Airplane Group, and Snecma. The purpose of the MOU is to define a common understanding with respect to the increasing importance, development, and usage of the product data standard STEP (ISO 10303). Copies of this industrial MOU can be obtained through NIST's ISO TC 184/SC4 Secretariat Office, Building 220, Room A240.

Type: Industry Support Letters

- Example: STEP Automotive Special Interest Group (SASIG) Letter of December 5, 1995. SASIG is comprised of four automotive associations (France, Germany, Japan, and USA), to further enhance cooperation with CAD/CAM product developers to support development and implementation of specific ISO 10303 application protocols. Copies of this industry support letter can be obtained through NIST's ISO TC 184/SC4 Secretariat Office, Building 220, Room A240.

Phase 2 - Analyze Requirements

Type: Requirements Specification for a Proposed Solution

- Example: Jurrens, Kevin K., James E. Fowler, and Mary Elizabeth A. Algeo, Modeling of Manufacturing Resource Information, Requirements Specification, NISTIR 5707, Rapid Response Manufacturing (RRM) Intramural Project, National Institute of Standards and Technology, July 1995.
- Example: Kline, Steven W., Mark E. Palmer, Group 1 for the Plant Spatial Configuration STEP AP, NISTIR 5675, National Institute of Standards and Technology, June 1995.
- Example: Kline, Steven W., Mark E., Palmer, et al, Process Engineering Data: Process Design and Process Specifications of Major Equipment Application Protocol Group 1, NISTIR 5909, National Institute of Standards and Technology, October 1996.

Type: Industry Data

- Example: Moncarz, Howard T., Program Requirements to Advance the Technology of Custom Footwear Manufacturing, NISTIR 5521, National Institute of Standards and Technology, October 1994.

Type: Literature Review

- Example:

Type: Standards Review

- Example: Pawlak, Craig G., A Survey of Standards for the U.S. Fiber/Textile/Apparel Industry, NISTIR 5823, National Institute of Standards and Technology, April 1996.

Type: Application Software Review

- Example:

Type: State-of-the-Art Assessments

- Example: Jurrens, Kevin K., An Assessment of the State-of-the-Art in Rapid Prototyping Systems for Mechanical Parts, NISTIR 5335, Rapid Response Manufacturing (RRM) Intramural Project, National Institute of Standards and Technology, December 1993.
- Example: Ressler, Sandy, Applying Virtual Environments to Manufacturing, NISTIR 5343, National Institute of Standards and Technology, January 1994.

- Example: Fowler, James E., Variant Design for Mechanical Artifacts-A State of the Art Survey, NISTIR 5356, National Institute of Standards and Technology, February 1994.
- Example: Algeo, Mary Elizabeth A., A State-of-the-Art Survey of Methodologies for Representing Manufacturing Process Capabilities, NISTIR 5391, National Institute of Standards and Technology, March 1994.
- Example: Moncarz, Howard T., Visualization Applications for Manufacturing - A State-of-the-Art Survey, Final Report, NISTIR 5427, National Institute of Standards and Technology, May 1994.
- Example: Algeo, Mary Elizabeth A., Shaw Feng, and Steve Ray, A State-of-the-Art Survey on product Design and Process Planning Integration Mechanisms, NISTIR 5548, National Institute of Standards and Technology, December 1994.

Type: Workshop Proceedings
- Example: Ray, Steven R., editor, Proceedings of the 1993 Industrial Process Planning Workshop, June 17-18, 1993, Gaithersburg, MD, NISTIR 5284, National Institute of Standards and Technology, October 1993.

Type: Identification of Potential/Appropriate Standards Bodies
- Example: Review of the ISO homepage for existing level of effort and functional coverage: http://www.iso.ch/welcome.html
- Example: Review of the ANSI homepage for existing level of effort and functional coverage: http://www.ansi.org

Phase 3 - Design/Develop

Type: Initial Strawman IMES
- Example: Sara Wallace, M. K. Senehi, Edward Barkmeyer, Steven Ray and Evan Wallace: Manufacturing Systems Integration Control Entity Interface Specification, NISTIR 5272, National Institute of Standards and Technology, Gaithersburg, MD, 1993.
- Example: Lee, Tina Y., Howard T. Moncarz, A Prototype Application Protocol for Ready-To-Wear Pattern Making, NISTIR 5115, National Institute of Standards and Technology, January 1993.
- Example: Kline, Steven W., Mark E. Palmer, Plant Spatial Configuration Application Protocol, Version 1.0 -- Volumes 1 & 2, NISTIR 5812, National Institute of Standards and Technology, December 1995.

Type: Information Model(s)
- Example: EXPRESS model of machine tool, cutting tool, and tooling components, Rapid Response Manufacturing (RRM) Intramural Project, November 1995.

Type: Interface Protocol(s)
- Example:

Type: Process Model(s)
- Example: Feng, Shaw C., A Machining Process Planning Activity Model for Systems Integration, NISTIR 5808, National Institute of Standards and Technology, March 1996.

Phase 4 - Validate

Type: Test Results
- Example: Smith, Mike, Swee Leong, Computer-Aided Manufacturing Engineering Forum, Second Technical Meeting Proceedings, Hilton Hotel, Gaithersburg, MD, August 22-23, 1995, NISTIR 5846, National Institute of Standards and Technology, May 1996.

Type: Prototype Implementation
- Example: STEP Tools, Inc: http://www.steptools.com/products.html
- Example: PDES, Inc. Pilot/Demonstrations: http://www.scra.org/pdesinc/deploy.html

Type: Test Environment
- Example: NIST's STEP Application Protocol Information Base Web Gateway to identify existing ISO 10303 application protocol requirements: http://elib.cme.nist.gov/apde/
- Example: Rosenfeld, David A., Reference Manual for the Algorithm Testing System Version 2.0, NISTIR 5722, National Institute of Standards and Technology, October 1995.
- Example: Mitchell, Mary, Initial NIST Testing Policy for STEP Beta Testing Program for AP203 Implementations, NISTIR 5535, National Institute of Standards and Technology, 3 November 1994.

Type: Test Suites
- Example: ISO 10303 Conformance Testing Service on-line tools through WWW: http://www.iti.org/cec/steptest/steptest.htm

Phase 5 - Build Consensus

Type: Reviewed/Harmonized IMES
- Example:

Type: Workshop Proceedings
- Example:

Type: Industry Review
- Example:

Type: Standards Development Organization Review
- Example: ISO/DIS 10303-202 ballot comments found on SOLIS: sc4/step/parts/part202/dis

Type: Industry User Group Interest/Actions
- Example:

Phase 6 - Transfer Technology

Type: IMES Final Report
- Example:

Type: System Demonstrations
- Example:

Type: Conference Presentations
- Example: Fowler, James E., Algeo, Mary Elizabeth A., and Kevin K. Jurrens. Computerized Representation of Manufacturing Resources: Statement of Need and a Proposed Solution, Proceedings of the Japan - USA Symposium on Flexible Automation: 1996, New York: American Society of Mechanical Engineers, 1996, Volume 1, pp. 695-697.
- Example: Algeo, Mary Elizabeth A., Fowler, James E., and Kevin K. Jurrens. Computerized Representation of Manufacturing Resources: Validation and Standardization Efforts, Proceedings of the Japan - USA Symposium on Flexible Automation: 1996, New York: American Society of Mechanical Engineers, 1996, Volume 1, pp. 699-702.

Type: Journal Articles
- Example: Jurrens, Kevin K., Mary Elizabeth A. Algeo, and Jim Fowler, "Beyond Product Design Data: Data Standards for Manufacturing Resources," published as Chapter 5 in Rapid Response Manufacturing: Contemporary Methodologies, Tools, and Techniques, Dr. Jian Dong (editor), Chapman and Hall, 1996.
- Example: Fowler, J.E., "Variant Design for Mechanical Artifacts: A State-of-the-Art Survey," Engineering with Computers, (1996) 12:1-15, Springer-Verlag London Limited.

Type: WWW Homepages
- Example: ISO 10303 short names database: http://www.cme.nist.gov/cgi-in/apde/sc4short.tcl
- Example: RRM Intramural Project home page: http:/www.nist.gov/rrm

Type: Vendor Implementations
- Example: PDES, Inc. STEP translator announcements: http://www.scra.org/pdesinc/vendor.html

Type: End-User Implementations
- Example: Production use of ISO 10303 announcements: http://www.scra.org/pdesinc/news.html

Type: Commercialization Plan
- Example:

Type: Toolkit Software Release
- Example: ISO 10303 conformance testing service: http://www.iti.org/cec/steptest/steptest.htm

Phase 7 - Initiate Standardization

Type: Standards Development Organization New Work Item
- Example: New Work Item for ISO 10303-227 (application protocol) and ISO 10303-327 (abstract test suite), "Plant spatial configuration."
- Example: New Work Item for ISO 10303-231 (application protocol) and ISO 10303-331 (abstract test suite), "Process engineering data: Process design and process specification of major equipment."

Type: Strawman Proposal Recognized as CD Status
- Example: Committee draft for ISO 10303-227, "Application protocol: Plant spatial configuration."

Type: Strawman Proposal for Standardization

- Example: ISO/TC29/W634 N4a, Part Library Data for Turning Tools: Contribution to ISO TC29/W634, J.E. Folwer, K.K. Jurrens, and M.E. Algeo, November 13, 1995.

Type: Standards Development Organization New Working Group

- Example: ISO TC29/WG34, for progressing the cutting tool aspects of the manufacturing resource data IMES.

Type: Amendment or Technical Corrigendum to Existing Standard

- Example:

Type: Implementors' Agreement/Profile

- Example:

Type: Project Plan and Schedule for Developing IMES Through Standards Development Organization

- Example:

APPENDIX E: Description, Roles and Responsibilities of Those Involved in IMES Process

SIMA Program Manager:
- responsible for implementing the IMES concepts, development process, and approval procedures within the SIMA Program
- builds IMES project requirements into SIMA Program milestones and schedule
- focal point for
    - information regarding various IMES development efforts
    - questions regarding the IMES development process or approval procedures
    - IMES presentations and marketing
- ensures SIMA Project Managers are responsive to the requirements of each IMES phase
- conducts annual assessment of published IMESs to determine whether the specification has been deployed by industry

IMES Document Champion:
- serves as editor of the IMES Concept Document
- works closely with the SIMA Program Manager and MSID Leadership Team to:
    - develop presentations and IMES marketing briefs
    - provide IMES presentations as necessary

Project Team:
Members working collaboratively under SIMA funding to develop an IMES to meet a particular industry need.

Project Leader:
Individual heading up the SIMA-funded project to develop an IMES to meet a particular industry need.

Industry Collaborators:
Representatives committed by an industry consortium or trade association to actively work with the SIMA project to develop an IMES.

Industry Reviewer:
Someone from industry with a vested interest to ensure his/her manufacturing requirements are met by the IMES.

SIMA Program Office:
The composite of staff under the management of the SIMA Program Manager.

NIST WERB Authorities:
NIST laboratory representatives responsible for ensuring WERB procedures are followed and quality publications are produced.

Standards Development Organization:
National or international organization whose primary purpose is the development and deployment of standards to meet industry requirements.