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Research, Development, and Acquisition

GUIDANCE FOR INTEGRATED PRODUCT AND PROCESS MANAGEMENT

VOLUME 3

TOOLS AND PRACTICES

PREPARED
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PREFACE

This Guidebook is a three volume set prepared by the U.S. Army Materiel Command to provide internal Army guidance for the implementation of Integrated Product and Process Management (IPPM).

This Volume covers supporting guidance. The primary user is the Army Integrated Product Team (IPT). Other users are those concerned with the management of the process, as well as, those responsible for the qualification training of people for the IPT. Volume 3 is a reference for the IPT to be used to support the application processes of Volume 2.

Volume 1 covers the concept and implementation of IPPM. It is managerial guidance and should be of primary interest to Army program/project/product managers, matrix support managers and managers of weapon system development. The secondary use is for leadership of the Army Integrated Product Team (IPT), as well as one of the tools for qualification training of people for the IPT. We have organized Volume 1 into five sections; Section I - Introduction, Section II - Organization and Resources, Section III - Acquisition Management, Section IV - Design Process, and Section V - Tailoring to Acquisition Strategies.

Volume 2 describes specific actions to be taken in IPPM applications. It provides operational guidance. We have organized Volume 2 into three sections; Section I - Purpose, Section II - Team Composition, and Section III - Integrated Product Team Life Cycle Responsibility.

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TABLE OF CONTENT

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LIST OF TABLES

TOOLS AND PRACTICES

Section I. INTRODUCTION

This volume covers the tools and practices that may be necessary to implement the principles of Integrated Product and Process Development (IPPD). Included is a list of tools and technologies and an IPPM assessment criteria action plan that can be used to assess the IPPD capabilities of a potential contractor. Finally, appendix A provides the Army's concurrent engineering strategy which covers the "Visions," "Goals" and "Ways" for implementing concurrent engineering within the Army.

A. IPPD TOOLS AND TECHNOLOGIES

Section II on IPPD tools and technologies describes the available or needed tools to comprehensively implement IPPD in a very large complex organization. Other smaller less complex organizations may require a less comprehensive IPPD tool kit. It is the intent of Section II to provide a shopping list of IPPD automation tools and technologies that can be used during source selection to evaluate a contractor's proposed method of implementing IPPD.

B. IPPD ASSESSMENT CRITERIA

Section III on IPPD assessment criteria is provided to further assist in evaluating the contractor's strengths and weaknesses in implementing an IPPD program. While Section II provides a shopping list of IPPD automation tools and technologies, Section III provides a measure of what is required against what the contractor has implemented.

C. CONCURRENT ENGINEERING STRATEGY

The action plan for streamlining the acquisition process within the Army consisted of ten "White Papers" covering various initiatives that outlined the visions, goals and ways to initiate this reform. One of these "White Papers" addressed implementation of concurrent engineering within the Army. Appendix A provides the "White Paper" entitled "Concurrent Engineering (CE) Strategy."

Section II. IPPD TOOLS AND TECHNOLOGIES

This section reviews the tools and technologies which are expected to have significant impact on the implementation of design automation systems which support IPPD and a assessment of four major IPPD attributes:

- Organization.
- Requirements.
- Communication.
- Product Development Methodology.

This section explains the desired functionality of specific design automation tools and technologies.

The design automation approaches proposed here can be categorized as follows:

Data and activity models.
Data management.
Integrated product development tools.
Design "view" support for multiple perspectives.
Decision support tools.
Management support tools.

This section also reviews some of the promising core technologies which provide a foundation for automation of a IPPD environment:

Predictive algorithms for early estimators.
What if exploration within requirements analysis.
Case-based reasoning.
Neural network adaptive learning algorithms.
Conflict resolution approaches.

A. TOOLS AD TECHNOLOGIES

Within the larger context of enterprise integration, there are several important linkages to Electronic Design Automation (EDA) tools and technology utilized within the IPPD environment for integrated product development:

Management Information Systems (MIS).
Computer Integrated Manufacturing (CIM).
Supplier-customer linkage.
Competitive benchmarking and market trends.
Integrated corporate information architectures.

These relationships are established at the end of this section.

1. Design Views. Design "views" are a concept for viewing a product or process design from different perspectives. This concept is fundamental for a proper understanding of a IPPD environment. Multiple alternative design views should be supported by the models, the tools, and the management systems discussed throughout this guidebook.

For product development teams to work "independently together," the perspective of each team member should be supported. The process of translating one perspective into another is often error prone.

2. Modeling Tools and Technologies. Models will continue to be required to provide a data structure for the design of products. EDA tools themselves are not useful without this input data. Meaningful performance analysis is dependent on accuracy of the models.

Quality and customer satisfaction are key objectives of any IPPD methodology, indicating the importance of accurately determining product requirements. Product features must be verified against performance requirements in a consistent and repeatable fashion. This necessitates comprehensive product modeling capabilities, which in itself contains new challenges.

Another important area is workflow modeling. This can actually be viewed as process modeling, but is segregated here for emphasis and differentiation from more traditional fabrication process modeling. Workflow models will be critical for the analysis of development processes necessary for continuous process improvement. Workflow models are the basis for comparison between alternative IPPD implementation and are also expected to be the basis of new project management, scheduling, and planning tools.

3. Process Models. Models of the manufacturing and support processes are required to support the concurrent design team. Processes should be designed in tandem with products, especially when the material properties are sensitive to process parameters. Process impacts on the design need to be assessed as well. Test is one of the first areas where we see industry wide standardization efforts of a new process (e.g., boundary scan testing). This approach was required because current approaches were not capable of handling increasing device complexity, rather than from any desire to achieve product optimization. Other processes are not currently perceived as being as difficult as test so little effort is expended on process improvement. A focus on concurrent product and process optimization should become a priority to motivate the standard-ization of improved processes for support, maintenance, etc.

4. Product Data Models. The increasing need to exchange product data between team members, organizations and companies has stimulated the development of standards for product data. The most widely known effort is Product Data Exchange using STEP/Standard for The Exchange of Product Model Data (PDES/STEP). In order to support the needs of multiple disciplines, STEP can accommodate different views and vocabularies. The data are assured to be consistent if represented within the structure of an information model.

5. Workflow Models. Workflow models have not been perceived as useful in the past, because flexible and adaptable descriptions of workflows were not available. However, workflow models will be required to describe systematic, repeatable processes. These repeatable processes are required for product optimization and to insure repeatable product success. Workflow models are descriptions of the sequence of processes and the inputs/outputs of each process. Most workflow tools, which are typically incorporated within framework software, track the interrelations between processes. This allows them to nullify analysis results when relevant changes are made to the product description. For instance, the layout of a printed circuit board can be nullified, or marked as erroneous, when an additional component is added to the schematic or an interconnection is changed. Workflow models are helpful in configuration management of product development data in large and complex development programs. Data sources can be linked with analysis results to insure coherency of the data package.

B. PRODUCT DATA MANAGEMENT

Product data management systems manage the data which is used within integrated product development. Here we are concerned with the management of data for consistency and accessibility. Much of IPPD methodology is focused on the integration of development perspectives.

For successful IPPD approaches to work well, it is a requirement that all team members have the ability to review and contribute to the design. This requires tool support for controlled access to work-in-progress designs. Current DOD requests for access to in-progress design data have highlighted network and design representation issues which should be addressed to effectively support this style of design. Work in progress data should be available across the design team during all phases of design, including requirements definition and conceptual design as well as detailed design and manufacturing phases. It is anticipated that there can be many approaches to providing access to this data, however, it is important to stress that balance across team members is critical. Team members requiring access to the design data need to be able to easily utilize the current data and they should be notified whenever other team members change the design in significant ways.

Other issues to be addressed in product data management include: the degree of integration of data sources, (which include frameworks, data storage policies, and standardization of design data representation), the scope of product data to be managed, such as design and process data, requirements and conceptual design data, corporate history, intention and access pattern data, decision traceability, required release data, and supporting process data. Another issue is the physical extent of data, both in sheer volume and in extent of distribution. Finally, aspects of data control and security need to be addressed.

1. Integrated versus Interfaced. Integrated and interfaced are two approaches to unifying sources of design data. Providing simultaneous access to work-in-progress data is infeasible in a scheme of interfaced tools. Interfaces expect that data requests can be processed serially and that data transactions are short. Lengthy transactions typical of product and process design/analysis functions and response to multiple, simultaneous requests requires true integration of data in order to enable IPPD. In determining when to move to full integration, a cost/benefit analysis should be performed on the impact of access delays and aged design data. Another force impacting the decision to integrate is the complexity of the coherency controls required to propagate changes and their impacts to all relevant data repositories. Segregated, interfaced schemes require complicated coherency mechanisms, while in an integrated system, update propagation is relatively simple.

a. Frameworks. Frameworks that allow design support tools to be "plugged" in and out of design environments are a requirement of any evolving design automation system. IPPD imposes no1additional functional requirements, but rather strengthens the requirement for "tool plugability." This is because tools will be evolving more rapidly in response to new waves of IPPD requirements to respond to incremental requirement refinements of traditional design automation - faster simulation, synthesis, behavioral level design, etc. In addition, IPPD's tailored approaches for each individual program implies that design automation support organizations will be involved in assembling customized sets of tools within a framework for each program. Tool plugability eases the support burden of that customization.

b. Standards. The most obvious approach to providing integration and tool plugability is through standardization of data exchange formats and methods for interoperability of tools such as a standard procedural interface.

c. Data Storage. Product data management schemes should support arbitrarily large and diverse development teams, so they themselves should be extensible, should accept product data of arbitrary type, size, and location. Additionally, to handle evolving IPPD implementations, data management systems should be flexible enough to absorb arbitrary extensions to existing data structures. These are requirements due to the nature of the previously uncaptured data which are now required in the integrated development process. This is particularly true for data generated during conceptual design and the initial capture of process requirements.

d. Level of Data of Design Objects. An issue closely related to design data storage is what piece of the total set of data is considered mandatory for the purpose of management and access? Design data to be accessed, shared and evaluated across multidisciplinary teams can be quite detailed. While this would not always be the case in every design decision, the design data should be accessible at the level of detail required. The smaller the discrete data item, the more overhead in managing it. The larger the item, the more overhead in using it. For design data integrity, product data should be managed at the same level it is accessed, and therefore modified. This is quite different than current file-based, release-oriented management schemes.

2. Scope of Product Data. In IPPD environments, the product data descriptions, requirements, and specifications are supplemented by process information, conceptual information, lessons learned, corporate history and a great deal of associated data. As the scope of the design process increases, the scope of the data required and generated increases as well. Information on available equipment and facilities, training and training aids, technical manuals and relevant requirements sources (Nongovernment standards, standard practices and procedures) will all need to be managed and accessed in an efficient manner. Traceability of design decisions to requirement sources is a beneficial addition to the environment which is enabled by the accessibility of requirements information.

Before we look at each of these in detail, we should consider the purpose of product descriptions. The primary purpose is to communicate important information about a product to others with a need and/or interest. Most current product data management approaches involve the control of raw data which does not address the primary communication needs. Capturing and storing the data and information needed to support product development is only useful if the relevant information can be identified and retrieved when it is needed and presented in a useful format. To understand what is relevant, when information is needed and in what form is it most informative, it might be helpful to study data access patterns within IPPD environments.

a. Design Data. Design data refers to the work-in-process description of the product under development. This is distinguished from models in that models are complete descriptions of the product under development or a complete description of a stand alone subset of the product. To support team development using a IPPD approach, design data should be accessible to all team members in incomplete states. In addition, design data should be presented in any view or perspective upon demand. To promote meaningful contributions from all members of the development team, all views should reflect the updated design representation as the design evolves. Management of this evolving design data, in all of its views is an unsolved challenge for IPPD; even more difficult are the personality issues related to data ownership. Depending on the dynamics within the development team, any given designer may feel at ease contributing his/her work in real-time, as it evolves or there may need to be protected scratch pads for the designer to work in, to try out unproven approaches prior to exposing them to team scrutiny.

Design data could also consist of multiple alternatives at varying stages of development. These also need to be viewed from multiple perspectives, so that all team members can add their contributions in a timely fashion in the format most suitable to their understanding and creativity. This imposes stringent requirements on multiuser access schemes. Many multiuser design systems currently available provide coordination between users by locking portions of the design at the data file or schematic sheet level. This is unworkable for a truly concurrent development effort. It is precisely the area under active development by one contributor that should be viewed by others who can provide constructive guidance.

Additional product data attributes should be added to the scope of the design data in order to accommodate the attributes which are of interest to the specialty engineers.

b. Process Data. Many definitions of IPPD explicitly refer to the simultaneous design of product and process. To satisfy this objective, the requirements for multiuser access, support for multiple views, and access to incomplete, work-in-process descriptions which were described for design data are also requirements for process data. Some examples of process data are processing sequences, tolerance models, assembly instructions, manufacturing equipment used, just-in-time schedules, deployment plans, maintenance policies, etc. Because there is so little experience in simultaneous design of products and processes, this document can only offer suggestions for an approach.

One approach for some classes of products is to generate the process steps automatically to achieve specified design features (such as the synthesis of a sequence of milling processes to fabricate a specified shape).

Another approach would be to maintain both product and process views which are synchronized. It is expected that one view could be considered the dominant view, where most of the development activity takes place. When one or more constraints cannot be satisfied, development activity would shift to another view. Development would continue to bounce between views, until all constraints are satisfied or even better, until an optimal design is found for the product and all related processes.

c. Requirements and Specification Data. Government emphasis is now to only define the required performance characteristics in terms of operational terms and then to require the contractor-government team to work together to evolve the design requirements (i.e., Requirements Evolution).

The conceptual design or system engineering phase accepts requirements as inputs and delivers specification as outputs. Tools to support system engineering or conceptual design are currently quite limited in capability, and in particular, do not support allocation or partitioning of requirements. However, automated support for partitioning is critical to effective multidisciplinary tradeoffs at the conceptual stage and to verify that specifications will indeed result in a product which meets the full set of customer and user requirements. Product data management system should maintain continuity between the product data and an unambiguous representation of the requirements and specifications including the source and rationale for all requirements.

d. Conceptual Data. The role of conceptual data is to represent a consistent description of the product and process at very abstract levels. This data will probably take several unconventional forms, including graphical descriptions of hierarchical decompositions, textural annotations, analytical results of tradeoff studies, behavioral descriptions of functions, tracing information to requirements, etc.

Conceptual design has typically not been captured electronically in the past, and has not been available to feed into more detailed design tasks. If this data and the supporting rationale were available, it would be very valuable in verification tasks and in decision traceability.

e. Lessons Learned. Lessons learned refers to information derived from past successes and failures, collected and organized to serve as guidance for future planning and product development. It is important to document failures as failures, and so, learn from past mistakes rather than repeating them.

f. Decision Traceability. Within a specific product development process, there is a need to capture the decisions made and their rationale so that other team members can efficiently review the critical decisions. This is important when the environment surrounding the product under development changes significantly during development, either due to lengthy development cycles or very dynamic environments. Decisions should be revisited to reestablish their validity. Traceability modules should be provided within any product data repositories to support this need.

Traceability modules also provides the additional benefit of enhancing communication within the team, by capturing the sequence of decisions explicitly, a physically dispersed team will understand the decision rationale. Decisions can be reviewed to determine that all relevant information was considered. Decisions which were made with incomplete or inaccurate information can be quickly reassessed in light of new information so that their impact on schedules, costs, technical characteristics, etc., can be adjusted accordingly.

A final benefit of decision traceability is the support it provides to product data base maintenance. Product features, attributes or requirements generated by a particular sequence of decisions can be quickly identified for removal or reconsideration when the decision spawning those attributes or requirements is reversed. Through decision traceability, automated tools could remove all artifacts of "old" decisions from the design.

3. Physical Extent of Data. Much of IPPD can be considered data driven in that the benefits of the approach will only be realized if all the members of the multidisciplinary team have access to accurate data. Therefore, management of the data is a critical success factor. Data management systems need to be well designed and in place, as one piece of an IPPD supporting infrastructure. As for products and process, it is necessary to understand the requirements for a data management system, in order to design it well.

a. Anticipated Data Volume. The volume of data which will be generated, and which needs to be managed, is massive. The role of the data librarian will be a significant one as organizations make the transition to increasingly sophisticated IPPD implementations. The importance attached to this role is an indication of whether the data management process is under control. Data management is critical to the success of an IPPD environment. Most approaches to IPPD involve coordinating or unifying decisions which were previously made in isolation in a sequential design process. In addition, most approaches advocate more explicit consideration of a broad range of data in the decision making. A consequence of these new approaches is the massive volume of data to be managed in a unified or coordinated manner. Contributing to this volume is the trend toward unifying data from multiple disciplines (test, reliability, manufacturability, etc.). On top of that, more soft prototypes are encouraged; where multiple alternative approaches to any given product or process are simulated and analyzed. Previously separate disciplines will attach domain specific data to each alternative design. To further complicate matters, additional data is contributed by the involvement of suppliers and customers. Still more information will be captured, as rationale, and lessons learned data are included. With shorted cycle times and large numbers of people involved in IPPD approaches, it is critical that this massive volume of data is efficiently managed. One approach will be the utilization of increased computer power to generate derived data as it is needed rather than storing all the data described above.

One specific category of data needs special attention - conceptual design data. There is a nearly infinite information which is not explicitly captured which drives initial product and process concepts. Implementation alternatives are considered and discarded (explicitly or implicitly), narrowing the amount of relevant information up to the point at which a specific implementation is selected.

b. Physical Distribution. In sophisticated IPPD approaches, data is generated by the most knowledgeable team member, as an integral part of his job and in a timely fashion. When the multidisciplinary team grows larger than the number of people who can be supported on a single workstation, data management schemes will have to cope with physically distributed data. In the cases where the team is widely dispersed geographically, (in different parts of the country or even the world) this becomes especially challenging, but no less necessary. This situation is inevitable if customer and suppliers are members of the IPPD team. The data management system will be required to handle frequent updates to physically distributed work in progress data, provide version management, synchronize updates and provide rapid response throughout the distributed environment.

c. Information Control. Critical in data management is a system to ensure the accuracy of the information. This involves validation by the responsible "owners" when information is committed into a management system to make sure it is correct and verification of the design when retrieved so that the correct information is delivered. The role of the librarian or a librarian system has increased importance in IPPD. This is due to the data centered nature of the concurrent information approaches, rather than the tool centered approaches of sequential engineering.

C. DESIGN TOOLS

To support IPPD, design tools currently allow the design engineers to make initial estimates of design characteristics, such as thermal profiles, reliability, supportability, etc., of their products.

In addition to product development support tools, tools and capabilities are required to support program management tasks. Product development methodologies cannot truly change unless program management methodologies (and therefore tools) change to reinforce the new approach. This is tied to the metrics used to track project progress.

IPPD design methodologies can gain a good deal of leverage from supporting design tools. These tools can be examined in two categories: improvements to existing tools and development of new tools. The first can be referred to as evolutionary advances while the latter are considered revolutionary.

1. Evolutionary Advances. Evolutionary improvements to the current state of design automation are those becoming available today or are similar enough to currently available tools to expect that one or more vendors will develop capabilities in response to the current market demand for IPPD support. These improvements include: faster and more broadly applicable simulators and Distributed Interactive Simulation, early invocation of support engineering analysis tools, improved and predictive analysis tools, standardization of tool interfaces and data representation, etc.

a. Better Analysis. Analysis tools should be able to determine the product characteristics as a function of a broad spectrum of design alternatives and variable parameters. Especially important are the characteristics of reliability, supportability, testability and manufacturability for both hardware and software. Analytical capabilities will have to be developed to accurately assess the impact of design decisions made on abstract product definitions.

b. Earlier Invocation. IPPD requires the invocation of analysis tools earlier in the product development cycle. For example, a preliminary producibility analysis can be performed on a tentative parts list, prior to Printed Circuit Board (PCB) layout. Additional producibility analyses could be run each time the design is refined.

c. Broad Perspective Tools. In may instances, input data can be marginally expanded to support simultaneous analysis by two or more similar disciplines. This has the advantage of providing feedback from multiple perspectives to the designer so that he can see multidirectional impacts of design changes. Also, the efficiency of Computer Aided Engineering (CAE) is improved due to the single pass through the data structures to yield multiple results, rather than each tool traversing the data structure separately.

d. Libraries. Distributed data libraries with centralized control to support multiple tools have the advantage of one-time-only input, verification, maintenance and access functions. Standardization of part libraries and support of component data by the component supplier will greatly reduce the amount of library support required from tool vendors. They should strive for compatibility with major part library vendors, rather than duplicate part library development staffs.

e. Interactive Design Rule Checking and Guidance. We are beginning to see a move to provide embedded design rule checking in "design data capture tools," such as schematic and layout editors. This can be expected to advance into interactive design real-time feedback and possibly to proactive, predictive design guidance.

f. Simulators. As computer power becomes more affordable, simulators have been enhanced to handle larger partitions of complex designs. Improved simulation techniques can be expected to improve the ability to handle analog effects in the same simulation run as digital effects. The capability to simulate analog, digital, microwave and software (i.e., the entire product) across partitioning boundaries is possible. Capabilities exist to simulate a complete electronic circuit and stress test the circuit using simulation. Weapon systems performance tradeoffs can take advantage of the Distributed Interactive Simulation technology to try out each desired characteristic in a simulated battlefield and then using the results to drive optimization.

g. Engineering Tools for Other Disciplines (Software, Mechanical). Due to the exploding costs and the "out-of-control" schedule impacts of software development, Computer Aided System Engineering (CASE) tools have gained some well deserved attention. This will continue until software development is well enough understood to be optimized and it will regain its position as just one portion of the entire product.

2. Revolutionary Advances. This section covers capabilities (tools and technologies) that are needed for IPPD but are currently not being investigated. Many of these required advances will be very difficult to make and/or will require significant Research and Development (R&D) investment, because the market need is not yet clearly understood. These areas are required and through time and familiarization with IPPD techniques, will be recognized as important. However, the development lead time is significant. It is important that research begin very soon to provide solutions for the anticipated bottlenecks in implementing IPPD. Revolutionary tools are those freed from the legacy of conventional tools and are architected for the purpose of providing multidisciplinary design guidance and design analysis. This is where we can expect to see real advances in blurring the boundaries between major disciplines, like engineering and manufacturing, hardware and software, electrical and mechanical engineering.

a. Data Centered Tools. The advantage of object oriented, data storage management is immediate access to inprogress data from multiple perspectives, extensibility of the information to be captured in the tools, the ability to transform between perspectives and the ability to both enter and view the data from various levels of abstraction. An extensible data storage manager centered provides the opportunity of using corporate owned data bases with vendor tools achieving interoperability, with the often proprietary data structures utilized by a specific tool. The advantage of this is that a product design (which is the intellectual property of the developer) is not in jeopardy when vendors upgrade tool releases. Tools and workstations do not have to be delivered to the customer when it is required that the design be delivered as well as the final product, (e.g., government contracts). This is similar to the DOD's move toward the Contractor Integrated Technical Information Services (CITIS).

b. Data Sharing. Data sharing is the concept of multiple team members having independent access to work-in-progress design data (usually from different perspectives) for review, analysis, modification, and annotation. This will require significantly more sophisticated mechanisms for data object locking/version branching and merger and concurrence across multiple copies of data.

c. Quality Metrics. Few metrics exist for determining and tracking product quality and its improvement. This serious deficiency needs to be addressed in order to justify investment into automated IPPD support and infrastructure costs. The specific IPPD approach selected for a specific product development program should be justified as any other business decision, i.e., with a cost/benefit analysis. Currently, quality improvements resulting from IPPD investments cannot be accurately quantified because a measurement basis for customer satisfaction has not been developed.

d. Tradeoff Metrics. A separate category of metrics are those to be used in tradeoff decisions involving several design disciplines. Multidisiplinary tradeoff approaches require comparative measures across disciplines. Currently a common basis for comparison between disciplines does not exist, such as testability and thermal. Most currently proposed comparisons involve a subjective or arbitrary translation to a common factor, such as time or dollars.

An important aspect of IPPD is to track the value added of activities in the IPPD environment. To do this, it is necessary to determine the aspects of product development which are valuable. An evaluation basis must be determined and the measurements should be indicators of the relevant value added.

e. System Engineering Tools. Errors made in the conceptual design and initial system engineering tasks have serious repercussions.

There are currently few broad capability toolsets which provide support for comprehensive methodical system engineering of the product. Rudimentary toolsets have been developed on an ad hoc basis and market demand is growing for such tools. Additional capabilities are needed to provide support in gathering and documenting the true and complete set of product requirements, traceability between implementation and those requirements, assistance in partitioning the functionality of the product into electronic subsystems, mechanical subsystems and software subsystems, and design verification. An area for future research is multidisciplinary optimization. This involved simultaneous consideration of all constraints, parameters and potential design alternatives as part of automated product optimization. Also needed are interfaced/ integrated conceptual design tools which produce an executable specification of a complex (hardware and software) system which can be validated against requirements. Partitioning tools would then extract hardware and software specifications independently and provide them electronically to detailed design tools. The detailed tools must have electronic access to requirements, conceptual design intent and verification tools to reexamine cross discipline design tradeoffs, to verify the correctness of detailed designs and implementation plans and to provide direction to detailed designers.

f. System Performance Specifications. The system specification area is composed of two separate features: There needs to be (1) an unambiguous executable language for expressing product and process characteristics, interpretable by the process action team and (2) an ability to ensure a correct-by-construction product which conforms to the system performance specification.

(1) Specification Language. For complex electronic systems, there is no executable specification language to describe requirements or specifications. An executable specification refers to a mechanism for describing and simulating a product during its conceptual phase. The purpose of the simulation is to determine if all the requirements have been captured, if the product meets all the requirements and if the requirements, as captured, are completely unambiguous and accurately reflect the concerns of the customer.

(2) Constraint Propagation. Constraint propagation is a technique to ensure that the design refinements satisfy system performance requirements and the performance specification. Constraint propagation methods need to include constraint relaxation to accommodate modifications in the performance requirements or specifications.

g. Documenting Relevancy. Design intent is used to annotate product and process information with decision rationale and other notations to facilitate reuse of design modules. Ideally, it is useful to allow arbitrary types of information to be added to the notation so that software fragments from emulators, parametric information, textual and graphic information can be included in the design annotation. The annotations should also include the known design impact of compromises, limitations, and conflicts, so that as constraints on the design are relaxed in the future, the design can be reoptimized. Research topics in this area should be focused on synthesizing design information which is captured as a natural part of the design process and then assimilated into information relevant to other designers who will be posing queries from a variety of different perspectives.

h. Planning and Scheduling Tools. Many existing scheduling tools are built on a foundations of sequential engineering and subvert the interaction, required within IPTs. New tools are required to determine optimal schedules for allocating resources to a project using a IPPD methodology. Also required are planning and scheduling tools for task tracking, progress monitoring, and ultimately performance review of team/individuals involved.

D. PERFORMANCE REVIEWS

Multiple design views to support the various team members in the perspective that they understand is probably the most productive approach. A single master version of the product data should be maintained which is unambiguous. From it, all the individual design views will be derived. To facilitate interactive discussions about design modifications, a view-to-view translator would also be helpful, although only required for performance reasons. In an ideal system, each team member is looking at his/her view in a separate monitor and updates to the design are automatically displayed in all views. One approach to supporting multiple design views is through a single, unambiguous view of the product which can be filtered to provide a specific perspective.

1. Definition of Perspective. The first question to be addressed is whose perspective should be supported. This relates to who are the team members and how key are their inputs. Ultimately, all team members are supported because you never know where critical inputs are going to come from, regardless of areas of expertise. This highlights the need to provide support for multiple perspectives. The same data and product design will be viewed from more than one perspective at a time, all of which could be under active modification. Obviously, this requires a scheme for managing multiple perspectives, for translating between perspectives and for synchronizing changes in various perspectives.

2. Who needs a perspective and does not have one? Customers currently have limited options for providing input into product development. DOD acquisition offices are beginnings to provide DOD customers with "window" into the active design. However, no relevant perspective has been defined to really support that customer. Commercial customers usually have no perspective at all. Neither does marketing. Infrequently, suppliers have perspectives supported in the design process. These viewpoints need to be supported to more effectively allow those functions to contribute to the solution. Issues of how the perspectives are to be created and how they should be presented still needs to be addressed.

3. Perspective Constraints/Alerts. Perspective constraints and alerts refer to the concept of providing information to other team members to let the other person know when he is being impacted. To enable something like this in its most grandiose form, the system would have some intelligence to understand when a proposed change would impact decisions made by another perspective, understand whether the change would violate the tenets held by that perspective, assess the impact in terms of those tenets and inform the individual of the proposal in terms of costs and benefits. This could be used to focus the negotiation to the specifics. This system would have to understand all the perspectives involved and go through this analysis for each perspective to bring all the appropriate parties together for the negotiation.

4. Representing all Relevant Team Members' Concerns. Techniques are required to easily capture and incorporate the users, purchasing, supplier, business enterprise, etc., perspectives. Some of the inputs may take the form of constraints on the project team, such as business policy or doctrinal parameters, while others are requirements or are unstructured suggestions. Capturing, structuring, interpreting and utilizing unstructured information is a challenge to current technology, unless it is captured as context-local annotation, where the person inputting the data determines structure and locality of relevance. User interface issues also become a challenge, particularly in situations of vastly unequal automation support.

E. DECISION SUPPORT TOOLS

Decision support is a broad topic and is used here in a non-traditional sense. Decision support refers to the collection of tools and techniques that aid product development team members to get a handle on the complex interfaces between constituent pieces of a complex product. Their purpose is to manage and aid in determining optimal values of product parameters. The following example of the interrelated nature of plated through hole attributes in printed circuit board design illustrates the multidisciplinary nature of the decisions to be supported. Although an oversimplified example, it demonstrates realistic tradeoffs between reliability engineers, mechanical engineers, manufacturing engineers, electrical design engineers, CAD engineers, and purchasing agents that could determine the success or failure of a product.

F. PROJECT MANAGEMENT AND SUPPORT TOOLS

Development of the project manager's perspective and its related support tools introduces some interesting issues of IPPD implementation. How does the purpose of a review and milestones change in a methodology of continuous value added? How do you determine relative performance of individual team members and determine the required skill mix within a team? When do you enhance the team with additional team members (when is the concept mature enough to bring in tooling experts, detailed designers, etc.). How do you compensate individuals within a team? In addition to tools to support ongoing program management, there are also tools required to support IPPD implementation planning. How do I assess whether my organization will be receptive to the IPPD implementation planning? How do I assess whether my organization will be receptive to the IPPD methodology changes called for in a new program? If they are not receptive, what steps will be required to effect the required change? The answers to these and similar questions will define the program manager's perspective and determine the types of tools which should be developed.

G. IMPLEMENTION ROAD MAP

In determining how to get started, before many of the tools and technologies discussed in this section are available, automation managers need some assistance in preparing an implementation strategy. This assistance should come from a strong statement of corporate values and beliefs which can be translated into tactical plans by each of the unit managers.

H. IPPD's LINK BETWEEN EDA AND ENTERPRISE INTEGRATION

While the bulk of this section focuses on EDA tools and technology to support IPPD, it should be recognized that an EDA system will not be isolated from the general strategy of enterprise integration, also called enterprise automation. The conjecture here is that, correctly implemented, an EDA system will form an integral part of any enterprise automation endeavor. Management Information Systems (MIS) and Computer Integrated Manufacturing (CIM) systems will impose requirements on EDA solutions to IPPD.

Section III. IPPD ASSESSMENT CRITERIA

A. OVERVIEW

Successful implementation of IPPD requires management and technical community commitment to the need for change. Once the commitment to IPPD is made, organizations need an action plan to know what to implement. Without specific information on the immediate targets of change, time, energy, and resources will not be committed. Management must establish an atmosphere that is conducive to the formation and implementation of IPPD. Throughout this section the term "**enterprise**" is used. The intent of this term is to use an organizational neutral expression that can apply to government, to industry, to government-industry teams, or other possible combinations. This section applies equally to any enterprise.

The difficulty to date has been in generating that clear set of targets. A broader "body of knowledge" or "common understanding" of how IPPD is applied to the individual facets of a project has been missing. Without this common understanding, change remains risky and benefits cannot be systematically assessed. With a shared body of knowledge, IPPD proponents become members of a larger community having common ground rules and vocabulary that allow sharing of ideas and concepts. The level of knowledge or understanding can then rapidly increase as contributions of members are accepted into the body of common knowledge.

The creation and dissemination of this common understanding is the goal of this section. Furthermore, the material is organized as a road map for projects seeking to implement IPPD. This road map takes the form of two matrices, both of which are essential to the assessment process. The first, (Critical Self-Examination) provides a mechanism for subjectively assessing level of IPPD appropriate to the goals of the program and its competitive environment. Nine "influencing factors" are defined with four levels of implementation complexity defined for each. Greater program complexity implies a need for a more comprehensive IPPD implementation for program success.

The second matrix, presents a consistent method for determining the required characteristics of the IPPD approach. Its rows represent the various facets of a program or potential project which are impacted or changed by IPPD. Each column describes an approach to IPPD. All approaches represent good IPPD practice, but each is a different style or scope of IPPD implementation.

The purpose of the graduated levels is to match the appropriate approach to IPPD implementation for a particular program to the needs of the program. The matrices can be used to several purposes: (1) determining the specific components of a IPPD approach, (2) generating an implementation road map to enhance IPPD capabilities, and (3) checking the consistency of the IPPD approach currently in place. All of these involve critical self examination.

1. Organization of the Chapter. This chapter is lengthy, containing a large amount of information about IPPD approaches and their application. An overview of the organization of this information is provided here to assist the reader in navigating through the subsequent sections:

- Part B describes the components of all IPPD approaches.
- Part C focuses on the factors which influence the selection of the appropriate IPPD approach.
- Part D and E contain the assessment matrix and the description of individual cells within the matrix, respectively.
- Part F illustrates the usage of the assessment matrix through an example.
- Part G and H review issues related to implementation of concurrent engineering within a project.

2. Assessing Project complexity - Critical Self-Examination. The necessary and sufficient level of IPPD capability is tightly associated with the nature of a particular program or project; and a set of influencing dimensions were developed to gauge the appropriate level of IPPD capability. By assessing the program requirements as high or low on the influencing dimensions, an organization can assess the level of IPPD capability that is appropriate for a program.

To illustrate this, consider a very complex, high-technology program that involves many people spread across organizational and geographic boundaries. This type of program would naturally require more comprehensive IPPD capabilities, while a smaller, less complex project could be accomplished with a simpler IPPD approach. An attempt to move the required IPPD environment beyond that level that is necessary and sufficient to satisfy the needs of a program and project will not necessarily add value to that program or project. Of course, once an organization has achieved a level of IPPD capability, it would not be prudent to purposely degrade its IPPD environment. This activity within the assessment process is critical to the correct interpretation of the second matrix.

3. Assessment. The assessment matrix is used along with a critical self-examination to generate an implementation road map and to check the consistency of a IPPD approach currently in place within an organization. By examining the description of every attribute (matrix rows) at each level (matrix columns), the "as is" environment is assessed. The road map is generated by increasing IPPD capability of attributes with characteristics to the left of the appropriate level desired or needed.

4. IPPD Environment. By completing an assessment of all IPPD attributes, the organization develops a snapshot of its IPPD environment. In a strict interpretation of the matrix, the program's overall IPPD capability is only as strong as its weakest IPPD attribute. The reasons for this is that a coherency was built into the matrix between the elements within a column. When a particular attribute is implemented at a lower level, this conceptually acts as a bottleneck, reducing the capability of the whole system. Because the matrix was constructed with highly interrelated elements, an attribute operating at one level is only feasible when related attributes have similar levels of capability. For example, immediate resolution of issues is not possible if issues are reviewed only on a periodic basis. For this reason, a cohesive and consistent solution is possible only when all attributes are implemented to the same level of capability, represented by a single column. The column represents a synthesis of the individual capabilities to provide a global view of an organization's overall ability to apply IPPD methods.

5. Road map for Improvement. Because all approaches describe good concurrent practice, the matrix is not intended as a rating tool. Whether a particular level is "good enough" for the needs of a program depends on the nature of the program. The environment has been designed to highlight weaknesses relative to a program's IPPD needs. By comparing the current environment with the "required" environment, areas for improvement can be targeted and plans can be developed to overcome those identified weaknesses.

It is tempting to anticipate the availability of automation technology as an enabler of IPPD, and this is addressed later. A careful reading of the matrix, however, reveals that IPPD is a new culture that must be instilled in team members. Automation of current, serial autonomous processes is a mistake and will only entrench current practices and stifle the mergence of a IPPD culture. Additionally, automation by itself is not the answer. Automation should be viewed as an enabler or facilitator of IPPD approaches.

6. What the Matrices Are Not. The assessment criteria are focused on program requirements -- what is necessary to develop a product. The matrix's assessment criteria are, therefore, applicable only to the program. The matrix is not meant to evaluate a company or a government organization or a functional group within an organization. The assessment matrix is to be used by an organization to evaluate its IPPD capability and determine its organizational needs relative to a specific program.

The matrix is a "snapshot" in time -- a best view defining an IPPD capability and what is needed. As suggested by the right most column, however, continuous improvement will, with time, cause new columns to be added to the right and eliminated from the left.

The matrix, its characteristics, and the influencing dimensions were developed in an attempt to describe specific characteristics which impact the successful execution of programs using IPPD practices. As more government organizations and companies gain experience with IPPD, additional insight will be gained into the key enablers and inhibitors of IPPD implementation.

B. IPPD DECOMPOSITION

IPPD is a broad topic with numerous attributes. In order to examine the relevant aspects in detail, it is necessary to decompose the total IPPD methodology into its integral components. Although this can be accomplished in a number of ways, the set chosen comprises: organizational issues, requirements, communication issues, and product development methodology.

Organization issues refer to aspects of team dynamics, strategic business issues, and management and corporate culture that affect product development. The organization and its culture must support a IPPD methodology for it to succeed. Existing cultural and organizational policies often counteract the intentions of IPPD. The matrix focuses attention on several specific categories of corporate culture and management policies that are crucial to successful adoption of IPPD methods and the systems engineering process.

A second major grouping deals with requirements. IPPD has broadened the interpretation of requirements to include all product attributes that impact customer satisfaction. Adequately capturing and expressing the total set of these requirements is crucial to IPPD. In addition, the matrix includes the need for planning, scheduling, and documentation of the product development team, along with validation of the total set of requirements are topics which must be worked in concert to ensure successful IPPD.

Communications is the next major category of critical IPPD capabilities. Communications is the lifeblood of an enterprise. Strategies and common goals must flow out to every individual to mold the team into an efficient and productive unit. Feedback from knowledgeable individuals is essential to optimize design decisions and to improve the development, manufacturing, and support processes. The communications capabilities are categorized by the types of information that are critical to IPPD. First are the broad organizational needs for data management and sharing within and between departments (for example, logistics, manufacturing, and design) and between suppliers and customers). Next is "lessons learned" which come from various organizations but must be interpreted and analyzed by an individual engineer in order to influence a particular program. Next is decision traceability, which refers to the capture of an "audit trail" of decisions and trade-offs that were considered during the development process, specifically the rationale for a decision, the other alternatives considered and the rationale for their rejection. Finally, interpersonal communication is considered to be the single, most important element of successful system engineering today. Individuals in an enterprise must care deeply about the success of the team and be openly receptive to improvement ideas and proactive in the dissemination of timely constructive assistance. Product development participants need to communicate several categories of information, such as working product data, lessons learned, decision rationale, and decision sequences. All are needed to track and optimize the process of product development.

Interpersonal communication and interworkstation communication are crucial and are related to how data is acquired and shared with the project, program, and enterprise.

The final major category is focused on the product development methodology itself. The process of concurrently enhancing the product and assessing its status are quite novel in a IPPD environment. In particular, optimization, verification, and development processes are redefined for IPPD. This affects the role of data libraries, reviews, and product architectures.

By breaking down the broad topic of IPPD into a more detailed list of critical components, this document provides a basis for assessing specific capabilities within individual programs to address the new approach to product and process development called IPPD.

C. INFLUENCING DIMENSIONS DESCRIPTION OF TABLE III-1

Since the level of IPPD capability is too tightly coupled with the nature of a program, a set of influencing program and product dimensions were developed to aid in gauging the approximate level of IPPD needed. Each dimension deals with a specific aspect of program complexity. The specific dimensions itemized has an influence on the recommended approach to IPPD. the aggregate of all influences determines the approach most appropriate for a specific program. The influencing dimensions are provided here and in Table III-1:

Product Complexity	Business Relationships
Product Technology	Team Scope
Program Structure	Resource Tightness
Program Futures	Schedule Tightness
Competition	

Each of these are described in the following paragraphs to provide a better understanding of the viewpoint and their dimension on IPPD.

1. Product Complexity. Product complexity is inversely proportional to the number of people who fully understand how the product works. Complex products, as an example, include those with electronic, software, mechanical and optical functionality where few engineers truly understand the full spectrum of the products functionality. Thus IPPD is essential. Complex products typically have many interrelated factors which make product design difficult. The identified levels of complexity are--

a. Designs that are assembled using readily available "catalog" parts whose interfaces are standardized and robust.

b. Designs that are assembled using mostly common parts with a limited number of items representing state-of-the-art parts.

c. Designs that contain key elements which are state-of-the-art or have large numbers of state-of-the-art parts with many sensitive interfaces.

d. Designs that push the state-of-the-art envelop. Managing interdependencies is critical to product performance.

2. Product Technology. Product technology refers to the availability of a base of capability or technology, which can be utilized in product design. The identified levels for technology are--

a. Product Designs utilize readily available technology.

b. Product designs require a new application of an existing technology, e.g., gears custom built for product.

c. Product designs require new capabilities from one or more core technologies, e.g., higher speed Integrated Circuits.

TABLE III-1: IPPD ENVIRONMENT INFLUENCING DIMENSIONS

	IPPD ENVIRONMENTS			
Product Complexity	"Catalog" Item	Mostly common parts, limited state-of-the-art	State-of-the-art items sensitive interfaces	Pushing the state-of-the-art
Product Technology	Avail Technology	New applications/ custom built	New capabilities from core technologies	New core technology
Program Structure	Small staff/informal communications	Moderate size staff, layered structure	Multiple locations/formal communications	Large size staff/deep reporting structure
Program "Futures"	No follow-on planned	Investment made to minimize costs	Investment span contractual boundaries	Significant future opportunities
Competition	Minimal	Significant barriers to market entry exist	Competitive analysis/market expansion	Active pressure/ competition to anticipate and react
Business Relationships	Arms length	Contractual	Teaming	Enterprise-wide/common goals
Team Scope	Dominant perspective	Competing dominant perspectives	Competing perspectives interrelated optimization	Aggressive optimization to meet requirements
Resource Tightness	Not severely constrained	Limited in-process resolution	No in-process correction	Tightly constrained
Schedule Tightness	Significant schedule slack time	Adequate for first pass success	Aggressive/ requires first pass success	Severely constrained
	A	**B**	**C**	**D**

d. Product designs require new core technology, e.g., Gallium Arsenide (GaAs).

3. Program Structure. Program structure encompasses the number of people, layers or reporting hierarchy, role of formal and informal communications channels, and physical distribution of program staff. Note: The structure represents what is NEEDED to execute the program, not necessarily how business is structured today (which tends to always look like category D in a large organization). This relates to how you WANT to structure a program staff. The identified levels for program structure are--

a. Program staff size is small with informal reporting hierarchies and communication channels. Program objectives are broadly understood by all team members.

b. Program staff size is moderate requiring layered reporting structures and more formal communications. Subgroups have specialized assignments. Informal communication channels are available.

c. Program staff size is moderate to large and physically distributed across multiple locations within a building or spread across buildings or sites. Communication channels are typically more formal with few informal means of communication.

d. Program staff size is large, with deep reporting hierarchies and structured communication channels and physically distributed across multiple companies, often across numerous organizations. Typically, individual assignments are narrow in scope and highly focused.

4. Program Futures. Program futures refer to the follow-on opportunities for the program in the minds of all team members. "Futures" deals with how much incentive there is to invest in the current phase to optimize product success in later phases or future products or, in other words, requirements for long range business decisions/investments. The levels for futures are--

a. Program is stand alone with no follow-on planned. No long term investments are required.

b. Investments are made to minimize recurring (e.g., labor saving devices/automation) and nonrecurring costs (e.g., hard tooling) plus are aimed at reuse. Available business base to payback investments.

c. Investments span contractual and business base boundaries. Investment risks are shared across the enterprise. Program end use criticality and life cycle product cost call for investment in reuse and future improvements.

d. Program is strategically aligned with enterprise, encouraging significant reuse in future generation programs, enabling significant future opportunities. Opportunities for mid stream (or in use) corrections are severely limited. Product has stringent end use requirements, e.g., nuclear power plants, lasers, etc.

5. Competition. Competition dimension refers to the level of activity in the relevant industry and the criticality of industry anticipating and reacting to competitor's moves. From the government viewpoint sole source procurement all but eliminate competitive pressures. This dimension emphasizes the need for flexibility of the program and its ability to react quickly to competitive pressures. The levels of competition are--

a. Competitive pressure is minimal due to few competitors or close business relationships between established business and their customer base, or protected (product or strategy) niche market positions.

b. Significant portion of available market is controlled by a few key competitors. Often significant barriers to entry exist.

c. Competing enterprises with significant resources channeled to competitive analysis and market expansion. Competitive benchmarking is extensive.

d. Active Competition with few barriers to entry, where there are significant pressures to anticipate and react to competitor's actions. Product introduction schedules and costs are critical as are features and other differentiators.

6. Business Relationships. This refers to the formality of the relationship between customers, vendors, suppliers, teaming partners and prime developers. The levels of relationship are--

a. Arms length relationship. Commercial transactions (buying and selling of preexisting goods) is primary form of interaction.

b. Relationship between business entities is formal and typically contractual. Directives governing business interaction are primarily unidirectional (One party has leadership role and typically dictates requirements to others).

c. Teaming relationship to achieve joint or complementary goals. Selectively engaging in bidirectional business relationships (e.g., consortia, strategic suppliers, joint development).

d. Customer, key suppliers, etc., are all working together as equals within the enterprise to satisfy relevant aspects of the program goals (establishing requirements and implementation approach).

7. Team Scope. Team scope refers to the diversity of critical perspectives required for program execution. This relates to the dominant product requirements. The levels of team scope are--

a. Small number of dominant perspectives (e.g., performance) with advice coming from numerous perspectives (e.g., test, packaging).

b. Small number of competing dominant perspectives which must be balanced to meet product requirements.

c. Large number of competing discipline perspectives involved in interrelated optimization.

d. Aggressive optimization required to meet total product requirements for the total life cycle.

8. Resource Tightness. Resource tightness refers to limitations in the staffing or funding available to the program. In some areas, resources can be used to counteract deficiencies in the existing IPPD methodology/environment. The levels of resource tightness are--

a. Resources are not severely constrained and are available to be applied to correct a program weakness.

b. Resources allowed for limited resolution of in-process problems.

c. Resources are not available for inprocess correction.

d. Resources are tightly constrained. Inadequate resources to execute the program leads to creative changes in the development process.

9. Schedule Tightness. Schedule tightness refers to the limited "schedule slack times" to counteract deficiencies in the existing IPPD methodology/environment. The levels of schedule tightness are--

a. Schedules include significant slack time on non-critical paths. Schedule is adequate for limited risk implementation. Trial/beta test product introduction time is available.

b. Schedule is adequate for first pass success. Schedule includes slack time on some noncritical paths.

c. Schedule is aggressive and requires first pass success.

d. Schedules are severely constrained. Mistakes cause significant schedule slippage, cost overruns and other negative business impacts (System fielding in catchup position).

TABLE III-2: IPPD ASSESSMENT CRITERIA

	IPPD ENVIRONMENTS				
	A	B	C	D	N
Organizational V.A					
Team Membership (Critical Members) V.A.1	---------- **Team Integration** ---------->				DYNAMIC CONTINUOUS IMPROVEMENT
	Members have task perspective	Members have multidiscipline perspective	Members have product perspective	Members have strategic perspective	
Team Leadership V.A.2	---------- **Effectiveness** ---------->				
	Management appointed team leader	Management selected team facilitator	Team selected facilitator	Natural emergence of temporary, most knowledgeable leader	
Team Member Contribution V.A.3	---------- **Synergism** ---------->				
	Segmented	Leveraged	Cooperative	Collaboration	
	Discipline specific HW/SW functionality	Interfaced tools and multi-disciplinary advisors HW/SW compatibility	Unified data model Central master multi	Computer-assisted cooperative product development	
Business (Key) Interrelationships V.A..4	----------**Participation** ---------->				
	Transaction based	Contractual	Joint Venture	"Partnership"	
	EDI	EDI	Frameworks	Integrated environment	
Training/Education V.A.5	---------- **Awareness** ---------->				
	Team concepts	Multidiscipline understanding	Cooperative decision Process	Synergistic knowledge discovery	
	Computer assisted instruction	Computer based training	Multimedia computer based training	Interactive simulation	
Responsibility & Authority V.A.6	---------- **Empowerment** ---------->				
	Member responsibility & rewards	Multidisciplined group responsibility/rewards	Team decision/responsibility	Team autonomy/reward	
Management Decisions V.A.7	---------- **Perspective** ---------->				
	Short term based decision/planning	Single phase planning investment	Multiphase planning & investment	Life cycle based decisions	
	Product unit cost accounting models	Design-to-cost accounting with risk management	Value-based decision support systems	Life cycle decision support systems	

TABLE III-2 (Continued): IPPD ASSESSMENT CRITERIA

	IPPD ENVIRONMENTS				
	A	**B**	**C**	**D**	**N**
REQUIREMENTS V.B					
Definition V.B.1	----------Thoroughness---------->				DYNAMIC CONTINUOUS IMPROVEMENT
	Itemized requirements definition	Requirements traceability	Requirements weighting	Unambiguous specification	
	Requirements data base	Traceability cross referencing	Multirequirement trade study capabilities	Executable specification environment	
Schedule Types V.B.2	---------- Parallel ---------->				
	Task duration - based schedule	Calendar - Based schedule	Event - based schedule	Continuous addition of value to the enterprise	
	GANTT Chart	PERT charts	Event driven program management tools	New scheduling paradigm	
Planning - Methodology V.B.3	---------- Adaptability ---------->				
	Bottoms-up collation of task definition	Top-down determination of task definition	Synchronization of concurrent, interrelated tasks	Iteratively refined abstract plans	
	Task management planning tools	Requirement satisfaction driven work breakdown structure	Interrelated process driven planning tool,	Environment - driven planning tools	
Validation (Specification to requirements) V.B.4	---------- Accuracy ---------->				
	Validation to itemized requirements	Validation of inter-related constraints	Validate to end use requirements	Validation of end use and product business strategy	
	Heuristic requirement fanout tracing	Heuristic interrelated requirement matrix techniques	Heuristic interrelated requirement matrix techniques	Simulation of executable specification	

TABLE III-3: IPPD ASSESSMENT CRITERIA

	IPPD ENVIRONMENTS				
	A	**B**	**C**	**D**	**N**
COMMUNICATION V.C					
Working Data Management V.C.1	------ Control ------>				DYNAMIC CONTINUOUS IMPROVEMENT
	Local individual data management	Data structured for project - wide sharing	Program repository of working data	Enterprise repository of working data	
	Workstation release control system	Configuration Management	Central program data base	Extensible data base	
Data Acquisition/Sharing V.C.2	------ Accessibility ------>				
	As needed data extraction	Data supplied by most knowledgeable source	Data available as generated. Program sharing	Enterprise - wide availability of data	
	Networked workstation with file management	Network communication	Central data base storage on program network	Central data base storage on enterprise network	
Lessons Learned Feedback V.C.3	------ Experience ------>				
	Design guides with rationale/intent	Consolidated design guide with rationale	Rationale & weighting for each product development rule	Dynamic lessons learned feedback	
	Checking with structured query capability	Checking with structured query capability/increasingly integrated rules	Checking with unstructured query capability with impact weighting	Checking with unstructured query capability and impact assessment	
Decision Traceability V.C.4	------ Legacy ------>				
	Individual decision rationale ownership	Project decision rationale ownership	Program decision rationale ownership	Enterprise decision rationale ownership	
	Repository with structured keyword search	Repository with unstructured keyword search	Repository with unstructured keyword search	Repository with unstructured keyword search	
Interpersonal V.C.5	------ Equality ------>				
	Member specific terminology	"Common" terminology	Equal input/impact	Knowledge - based perspective	
	Electronic communication	Multiple view (jargon to jargon translator)	Knowledge based cross discipline advisors	Knowledge based generative tools	

TABLE III-4: IPPD ASSESSMENT CRITERIA

	IPPD ENVIRONMENT				
	A	**B**	**C**	**D**	**N**
Product Development Methodology V.D					DYNAMIC CONTINUOUS IMPROVEMENT
Optimization V.D.1	---------- **Customer Satisfaction** ---------->				
	Review based optimization	Limited interrelated requirement optimization	Program wide requirement optimization	Total weighted requirement optimization	
	Single requirement optimization	Multiple requirement optimization	Multiple requirement optimization	Weighted multirequirement optimization	
Data Libraries (single master library source) V.D.2	---------- **Consistency** ---------->				
	Control of preferred parts and process libraries	Controlled libraries of reusable module and intent	Controlled technology independent libraries	Controlled real-time library data from source	
	On-line libraries, selection assistance	Program-accessible networked library	Technology information external to tools	Technology information external to tools	
Development Process V.D.3	---------- **Controllability** ---------->				
	Product independent, repeatable and consistent process	Measurement standards definition	Closed loop control	Process improvement and optimization	
	Consistent process methodology enforcement	Key parameter identification tools	Integrated process methodology	Integrated process optimization	
Reviews V.D.4	---------- **Non-interruptive** ---------->				
	Schedule driven product and process critiques	Event driven review	Immediate issue resolution	Status reporting	

TABLE III-4: IPPD ASSESSMENT CRITERIA

	IPPD ENVIRONMENT				
	A	B	C	D	N
Product Development Methodology V.D					
Measurements V.D.5	---------- Information Content ---------->				
	Measurement using function specific deterministic indices	Measurement using process related deterministic indices	Measurement using heuristic predictive indices	Measurement using relevant, analytical, interrelated predictive indices	
	Information systems handle project requirements	Expanded info. system to include process	Statistical process control	Integrated, enterprise wide factual data	
Analysis Architecture V.D.6	---------- Hierarchical ---------->				
	Single level modeling	Multidiscipline verification	Team verification	Correct by construction	
	Single level simulation and analysis tools	Multidisciplinary analysis tools	Compliance monitoring	Compliance assistance	
Verification V.D.7	---------- Compliance ---------->				
	Member dependent verification	Multidiscipline verification	Team verification	Correct by construction	
	Complete suite of analysis tools	Multidisciplinary analysis tools	Compliance monitoring	Compliance assistance	

D. MATRIX

The actual assessment matrix is provided in Tables III. The assessment matrix was developed to provide guidance on determining the level of IPPD environment presently implemented versus the indicated level defined by the program's influencing dimensions. A road map is also provided in the establishment

TABLE III-5: SUMMARY OF IPPD Assessment CRITERIA

ATTRIBUTES OF IPPD:	THEME
ORGANIZATION	
Team Membership	Team Integration
Team Leadership	Effectiveness
Team Member Contribution	Synergism
Business Interrelationships	Participation
Training/Education	Awareness
Responsibility/Authority	Empowerment
Management Decisions	Perspective
REQUIREMENTS	
Definition	Completeness
Schedule Types	Parallel
Planning Style	Adaptability
Validation of Specs to Rqmts	Accuracy
COMMUNICATION	
Management of Working Data	Control
Data Acquisition and Sharing	Accessibility
Lessons Learned Feedback	Experience
Decision Traceability	Legacy
Interpersonal	Equality
DEVELOPMENT METHODOLOGY	
Optimization	Customer Satisfaction
Data Libraries	Consistency
Development Process	Controllability
Reviews	Noninterruptive
Process Measurements	Information Content
Analysis Architecture	Hierarchical
Verification	Compliance

of the needed environment. An IPPD environment can be generalized into four main categories:

Organization
Communications
Requirements
Development Methodology

These main topics are subdivided in the matrix to aid the evaluator in assessing the current environment. A summarized assessment matrix is provided in Table III-5 to give the reader some insight into these key considerations. The following section on Matrix Description will provide a definition of the overall matrix.

E. MATRIX DESCRIPTION OF TABLE III-3

The assessment matrix is divided into four main categories each of which are subdivided to provide further detail and definition. The following paragraphs define the IPPD categories and their subcategories.

Within the matrix categories are shaded areas and within the following paragraphs are italicized areas which provide an automation road map to each applicable topic. Automation is not an IPPD requirement but is definitely an enabling capability. From this enabling viewpoint, an automation road map is provided to give insight into this fast paced technology.

1. Organizational. An enterprise's organizational maturity is defined by the structure and dynamics of its teams, its business relationships, and its decision-making apparatus. As product complexity increases, the enterprise must seek a tightly knit structure that includes team members across the enterprise, including both internal and external resource.

a. Critical Team Membership (Team Integration). In product development, a collection of individual experts must combine their efforts as a team. For increasing levels of product and process complexity, the critical dimension is a tighter integration of the team and not just its co-location (real or virtual).

Level A: Individuals with Task Perspective.

This level involves individuals with specific task and discipline orientations. A limited number of team members have the big picture. Those who do are usually responsible for system integration. The emphasis is on performing a specific task with little interaction between other designers and other organizations and subcontractors. An elementary level of teamwork is present by virtue of designers having some input from the team members.

Level B: Individual with Project Wide Perspective.

The perspective of the individual encompasses a project perspective. The use of structured teams with advice from consultants is prevalent. Multidisciplined training aids communication. The members see the necessity to obtain outside expert assistance. The core membership tends to still be parochial in their expertise. Small team of integration experts are present.

Level C: Program Wide Membership.

The team membership includes other disciplines within the program. The team uses various tools and data that require multidiscipline approaches. Awareness training has allowed team members to understand each other better and appreciate the value of different disciplines to be on the team and the inclusion of some in-house experts on the team. The inclusion of advisors and suppliers is prevalent. All team members feel responsible for integrating inputs.

Level D: Enterprise Wide Team Members.

This level involves membership that comes from the entire enterprise. The team takes a holistic approach to the design activity. The team is cohesive. Whenever possible, membership will include management, suppliers, manufacturing, purchasing, representatives of different types of customers (STRICOM, TRADOC, etc.), inventory management, ILS engineers, safety/human factors specialists, reliability, environmental testing, maintainability, testability, quality assurance, and other principals as required. The team members are sensitive to impacts not just on design, manufacturing, and support but on financial and schedule issues as well. Team aggressively solicits all needed inputs to facilitate proactive integration tasks.

b. Team Leadership (Effectiveness). The effectiveness of a development team depends on its leadership structure from one imposed by management to one selected by the team members themselves.

Level A: Management Appointed Team Leader.

Management is learning about teams and the level of teamwork expertise in the organization is low. The concern is effective leadership for teams. Management will customarily send key individuals for leadership training and appoint team leaders. The leaders are usually interested in a discipline-oriented and task-oriented style to achieve a predetermined goal using team concepts. Segregated task assignments reinforce that the leader is the only one(s) with the big picture perspective. Team leader strives to educate team on the big picture and solicits relevant inputs to work for consensus.

Level B: Management Selected Team Facilitator.

Management has determined that while the appointed leader is working hard, the team can drift and/or does not have anyone to "teach" it techniques that may be required. Management will usually send more key individuals for facilitator training and appoint these individuals to teams. The facilitators will come from various parts of the organization but have specific personality traits or background/training that makes them acceptable to the team.

Level C: Team Selected Facilitator.

The organization has a number of trained facilitators as well as employees who have had basic team training and experience serving on teams. The employees have served on multiple teams and are familiar with the available facilitators. It is common at this level to have the teams request/select their facilitator based on their mutual experiences, background of the facilitator, and personality. These teams are more experienced and know the mechanics of working as a team. The leader(s) usually rise out of the team rather than be appointed by management.

Level D: Natural Emergence of Temporary, Most Knowledge Leader.

Teams will sometimes self originate. This necessitates the emergence of temporary leaders based on the knowledge and leadership required during specific phases of their work. Even if a team is appointed, the leadership emerges from the group. As in the Acceptable level, the facilitator is selected by the team. Teams that are appointed are usually done in a loose manner with specific objectives and time/cost goals set, with the team organization, membership, leadership and facilitation left to the team.

c. Team Member Contributions (Synergism). IPPD environments are characterized by synergy in the interaction among the individual members of the team. Without synergy, the interaction tends to occur between relatively isolated domains of expertise but with synergy, the isolation is eliminated.

Level A: Discipline Oriented Contribution.

A heavy individualistic approach to work is evident. Teams, formed as a group of individuals, struggle not only to produce the desired output but also to have the output contain each individual's mark. The teams also tend to be discipline-oriented in function and output plus use little outside assistance.

Designs are checked by resident experts after the design concept and detail design are complete. The design is submitted to a review cycle for the expert to pick it apart. In some cases, only major faults will be corrected, since most changes are not allowed due to schedule constraints. The designs may be reviewed by multiple experts based on the complexity of the design. There are usually delays due to availability of experts and serial handoffs.

ENABLER: Discipline specific hardware/software functionality.

At this level, computer tools and hardware/software are discipline-specific. The input is usually manual and the computer is for specific applications. The level of influence and capability varies from department to department along with the type of hardware and software.

Compatibility with other organizations is not considered important. Data is reentered or translators are developed.

Level B: Expert Consultants Provide Advice.

Experts act in an advisory role to the team. Some of the advisors may be assigned to a team full time, others part-time. Here the experts try and act on the design during the actual design process.

The teams have a wider perspective and more experience. The need for multidisciplined teams is evident and their use is common. Organizations realize they cannot have all the expertise they need dedicated to all the teams at the same time, so expert consultants provide advice on an as-needed basis. The expert is sometimes viewed as a nonequal as are some team members. The consultant is often deemed on a higher level than the team itself. The experts are usually people with unique backgrounds that are needed across the organization, but the company cannot afford very many of them. By operating in this manner, an organization gets the assistance it needs at a reasonable cost while it facilitates the necessary awareness training of team members.

ENABLER: Interfaced tools and multidisciplinary advice.

Project team hardware/software compatibility. Interdisciplinary concerns are paramount to the enterprise. The organization is concerned about what data needs to be transferred, translated and reformatted and has realized that the hardware and software need to be more team-supportive and user-friendly. Data is translated and transmitted from one discipline-specific system to another, but the systems are not truly interactive. Tools communicate through neutral formats or via tool integration framework.

Level C: Team Member Equality.

This level has equality across the team. The team members have experience and training, and recognize valuable contributions of their peers within the team. The members see themselves as equals and distribute the assignments based on knowledge, expertise, and need, rather than on title or regular job function. "Who is the most qualified" becomes the issue, not "what department do you represent."

In-house experts are members of the design team. Suppliers are brought in as consultants during the actual design phase rather than after the fact. The objective is to use in production the same suppliers that helped with the design. The suppliers can give ideas and show how to reduce cost based on their expertise and process.

ENABLER: Unified data model and central master data bases. The organization gets into unified data models and a centralized or distributed data base with hooks and links to make the systems function as a single data base. Object-oriented data base management systems are the systems of choice, but must interact with many types of heterogeneous data bases. Compatibility between platforms and systems and platform/system invisibility are key issues. Design environments that offer open architectures and multivendor supportability are important.

Level D: Synergy.

People work together as a well-oiled machine-- competent not just individually but collectively. They utilize the collective strengths of the group and obtain outside assistance when needed without hesitation. This organization is experienced and confident and is spending almost all its efforts on the objective and little on the mechanics of team interaction because the mechanics are a way of life for them.

We can think of the team as a holistic design activity. We have all principal parties participating, including engineers, vendors, customers, management, manufacturing, purchasing, etc. The most knowledgeable person at the moment acts as the temporary leader. The team can now take on the whole system and where their parts fit into the rest of the design. This simplifies the interface between items. Computer-assisted cooperative product development is evident.

ENABLER: Computer assisted cooperative product development. The computer is interactive. The systems offer a product-wide or organization-wide network with people/design/ manufacturing/support data integration. The systems support specific functions and allows a multidiscipline approach to design, manufacturing and the business enterprise. System actively identifies inconsistencies between disciplines or subsystems.

d. Business Relationships (Participation). The degree to which external resources participate as team members in product development is critical. External suppliers and customers need to participate fully in product development.

Level A: Transaction Based.

The interest in business issues and relationships is negligible. The interchange of material between functions is primarily formalized through paper text, with very little sharing of in-process data. The transfer of data occurs only when data is considered complete and in an acceptable format. Reports, presentations, business-related data, and the like are passed on from one group to another as primary communication of requirements, needs, its use, or the end user. The interchange is by procedure or formal request. Request for development material is made by purchase order.

ENABLER: Electronic data interchange. Automation exits within individual entities, usually with manual input from a paper trail. Released data is downloaded in batch upon formal release.

Level B: Contractual.

The awareness that other organizations exist and have specific needs for data. In some cases, the ability to see "in-process" work is realized. The other organizations start to have sporadic involvement. Communication take place, and cross- cultural barriers dissolve. The realization surfaces that intercommunication will provide mutual benefits. Specific requirements and tasks are defined by contract to subcontractors.

ENABLER: Electronic data interchange. Electronic interchange implementations are ad hoc. The product developer and the supplier are beginning to use the computer to collect information in its data base. They are communicating and tying the organizational needs together in one place. They provide cross-organizational islands of automation and on-demand access to work-in-progress data.

Level C: Joint Venture.

The intercommunication of technical data occurs on a quasi-real-time basis. Business and program involvement takes place, data is interchanged and communication links are expanding. Other organizations' need for the data and their use of it is better understood and can be structured in some instances to aid the various users. People are involved, consultants are necessary, and an attitude of peers working together is established. Every team member understands the need to respond promptly to requests for information or data. Joint venture and partnerships may be formed that divide the tasks and responsibilities. A very close business relationship exists.

ENABLER: Frameworks. Computer data bases are networked together to form the intercommunication of technical data. A framework is put together where technical data can be transferred electronically between the data supplier and the data users. Team members have interactive access to work-in-progress data. Automation support is compatible across team members.

Level D: Total Involvement.

This level involves the whole enterprise -- many levels and departments, some outside the limits of the program. The relationship between internal and external business partners is understood and people are accepted as peers. Thus, communication is easier, barriers such as department lines and job titles are broken down and the best person to handle a task is asked to do it. Exchange of data is freer because of the awareness training of people, the networks of communication and the mutual understanding of need. A major guiding factor becomes a view of the whole and how individuals fit in and contribute.

ENABLER: Integrated environment. Total integration of all the organizational needs have been captured in the computer data base. Networking of computers has been accomplished which now allows interactive participation by the external suppliers and customers. The whole enterprise is in a totally integrated and interactive process which can be directly addressed. Team members have equivalent and compatible levels of automation. Automation systems have ability to generate alerts to solicit required inputs and reviews.

e. Training/Education (Awareness). The focus of training broadens beyond individual disciplines. For team members, this permits a greater awareness of enterprise issues.

Level A: Discipline Oriented Specialists.

Individuals are trained in specific specialties and lend assistance whenever the need for that particular discipline is required. There can be problems. This occurs when one specialist wants to do something that is best for that particular area of the design but causes problems in another area (discipline viewpoint).

ENABLER: Computer-assisted instruction. The computer is used to try out concepts or to handle computations being taught by other media. The computer assists the instructor with instruction material and is an instruction tool much like a textbook, calculator or drawing board. Training is usually focused on the use of systems and specific rules/policies.

Level B: Multidiscipline Awareness.

People are trained in multiple discipline awareness when possible. Similar results can be obtained by co-locating specialists that are concerned about a particular design, encourage interaction to better understand each others needs, and the impact each discipline has on the other. This constitutes on-the-job cross training or awareness training. In this manner, as people move from one team to another they become more well rounded.

ENABLER: Computer-based training. The computer is acting as the basis for the training. The computer becomes not just a tool but the instruction material itself. The increased interoperability of systems becomes a key factor. The computer is the tool needed to operate on designs and/or business data, therefore the computer is used to aid in the actual training. The meanings, intentions and applicability of rules is often the focus of training.

Level C: Team Effectiveness.

An effective team exists based on training in team mechanics, effective communication, and Total Quality Management (TQM). The team members achieve some synergy between team players. here the specialists have a somewhat broader knowledge base and are using tools that bring the critical thoughts together through such things as Quality Function Deployment (QFD), Design of experiments (DOX), etc. Teams understand concepts such as Design to Unit Cost/Life Cycle Cost and Design for Manufacture. People consider things normally outside of their perceived responsibility. Training is on-demand and situation specific. Training materials are usually self-guided explorations used on an as-needed (just-in-time) basis.

ENABLER: Multimedia computer-based training. Here the use of multisystems and different instructional media controlled by the computer is used to present real life training as opposed to single CRT display interaction. The ability to conduct an activity on a computer and then work the results on different types of equipment is imperative to handle actual conditions. This can include learning to design a part on a CAD system and in hours have the part from a computer-driven plastic modeler.

Level D: Synergistic Knowledge Discovery.

The team is autonomous. The team is given the overall goals, limitations, schedules, and budgets with management review dates and the tools to do the specific job(s) it is expected to accomplish. The team acts as a design house managing their own functions and interfacing with other teams to mutually accomplish a design goal. Management provides not just the items named above, but the responsibility and the authority to accomplish the goals.

ENABLER: Interactive simulation. Just in time training may be suggested by system and may take the form of self-guided explorations. System may force further exploration to ensure complete training as necessary. This level involves the use of interactive simulation. Here simulation where various functions can visualize the part being designed in a solid 3D model and simulate the process anticipated to make it. Here we can locate design issues, special tooling, and predict costs. We can also conduct "what if" simulations and arrive at a "best solution" for a specific design. The simulations can be accomplished by multiple users with different perspectives and views. Therefore, it is important that they understand the system use. By having interactive simulation a new person can learn the methods of data generation and storage handling in a safe environment. New perspectives can be generated to force examination of issues from different perspectives. Tools provide translation between perspectives, analogous to geometric translation between axis.

f. Responsibility/Authority (Empowerment). The team is empowered to implement its decisions. With this authority comes the responsibility for the decisions, plus motivation and rewards come to the team as a group rather than as individuals.

Level A: Individual Responsibility and Rewards.

At Level A the responsibility is at the individual level. Here each person is responsible for the accurate and timely response to an issue. The individual is also responsible for his or her quality. It is assumed that each person has a product and/or service and that person is responsible for the satisfaction of the consumers of their products and services. Management reserves the right to countermand decisions or review individual decisions at a detailed level.

Level B: Multidisciplinary Group Responsibility and Rewards.

At the B Level the group or team assumes the responsibility for the quality of their product and the individual is a subset of this responsibility. The importance of the quality of the output of the individual is not diminished but is part of a collective effort toward the common goal of the team. The team has the overall responsibility and the authority to accomplish the goal and the individual receives whatever responsibility and authority he/she needs from the team. Team success is viewed as a requirement for individual success. Management retains strong inputs and determines specific rewards. Management can reward "lone ranger" heroes.

Level C: Team Decision and Responsibility.

The individuals, working together, make the major decisions and assume the responsibilities and authority as a group. The individual, while still having responsibility is now playing a gibber role in the group and helps form a group mentality. Rewards are viewed from a team perspective and the team allocates rewards to individuals.

Level D: Team Autonomy and Rewards.

Here we have a self-functioning team that has a function, group authority and responsibility. The team is looked at as an entity and the individuals achieve identity from the team. Rewards are established by how well the team functioned so applicable rewards are given to the team. While individual participation is mandatory, heroes are not viewed in the same light as before. Here the hero is not rewarded if the team fails. This forces people to overcome personal issues and pull to accomplish a common goal.

g. Management Decisions (Perspective). Management perspective motivates the scope of decisions. Management perspective broadens beyond short-term concerns to a stage that accounts for the total product life cycle.

Level A: Short-Term-Based Decisions and Planning.

Management plays a big and direct role. Here the direction is detailed and management is involved in the short term decision making and planning efforts. The team sometimes does not know the long term plans. Suboptimal decisions are made due to the limited visibility. Preplanning is almost nonexistent. Short term return on investment and rapid payback are dominant concepts. Zero-based budgeting/calendar-based planning, and budgeting/forecasting with cost and profit center organization are typical.

ENABLER: Product-unit cost-accounting models. Product costing at this level follows historical accounting methods and is focused on product unit cost. Even this data is difficult to obtain and usually cannot be used by design teams. The cost data does not provide insight into where the cost drivers in a design can be found. The data is aggregated to product cost level with a fairly substantial error factor involved. Material roll-up tools are typical.

Level B: Long-Term Planning and Investments.

The organization conducts longer term planning with planning being wider in scope. Planning covers multiple disciplines and a longer product life cycle. The "big picture" is clearer and investments are made in planning and resource allocation. Historical cost perspective is dominant concept.

ENABLER: Life-cycle cost-accounting with risk management. The need for cost data is obvious. Life cycle cost data is considered part of the unit/system cost considerations. Risk management assessments are factored into the life cycle cost and into the pricing models. There is the ability to get real units cost. The team has access to the parts cost history file and labor cost history.

Level C: Multiphase Planning and Investments.

The team performs product life planning and downstream improvements. Organizations invest in resources and planning for a multicontract approach and consider items that will have impact in years to come. This is a multiphase, multiyear approach that considers the best value design for the customer and for the enterprise from the perspectives of quality, cost, supportability, and fitness for use. Value-based costing with new payback assessment mechanisms are dominant decision concepts.

ENABLER: Life-cycle decision support systems. Life cycle costs and life cycle design issues are important. Methods exist for doing Design for Manufacturability and design to cost studies. The organization has developed a good cost history and projection system. Design teams have the cost, life cycle and quality goals specified and the tools to evaluate their activity. All life cycle cost/use data is available to the team, and the accounting system has been structured to aid the team in decision making with a true assessment of value.

Level D: Best-Value-Based Decisions.

The organization has established a measurement data base of product and productivity information. Lessons learned from experiences and knowledge gained has shown the way to make improvements. Changes are made with little or no effort. Prevention of defects have been enhanced to the point where very few are encountered. Measurements of quality, reliability, maintainability, survivability, etc., are obtained and easily predictive. Functioning feedback loops are in place to analyze and measure programs and their development processes to improve performance.

ENABLER: Best-value decision support systems. The life cycle program is well established and we are pursuing the value added based support system. Computer simulation is used in design and manufacturing as well as field service to minimize the non-value-added tasks in the design, manufacturing, and support processes as well as the unique components in a design. The concept of value added and new definitions of waste are a part of the culture.

2. Requirements. Requirements refer to external and internal constraints and assertions which impact development of products. These external and internal drivers are categorized here into the following types: product definition, scheduling capabilities, planning methodologies, validation plans, and documentation generation.

a. Definition (Completeness). Product definition can be thought of as the process of capturing and translating customer needs/desires and internal needs into the specification of product and process features to satisfy complete life cycle needs. This includes all requirements, such as manufacturability, supportability, and upgradeability.

Level A: Primary Requirements Definition.

The product definition completely captures the primary product attributes. These are the most important needs/desires which often directly impact purchasing behavior - primary function, performance, cost, etc. Requirements are often driven by market differentiators.

ENABLER: Requirements data base. Requirements data base is established that is accessible to team on demand and the customer participates as a team member to clarify requirements.

Level B: Requirements Traceability.

These primary product attributes are addressed and the capability of tracing directly from a product feature to the specific care-abouts that spawned it is available. This enables flexibility in reacting to changing requirements. QFD's House of Quality is an example of the capabilities in this environment.

ENABLER: Traceability cross-referencing. A QFD type capability that allows for flow-down and flow-up linking of requirements and requirement sources. Interactive traceability and change impact assessment tools are available.

Level C: Specification Value Weighing.

Consistent (repeatable) methodology is provided to systematically tradeoff between conflicting requirements. This capability enables requirements beyond the purchase behavior care-abouts to be addressed successfully. Often corporate policy, manufacturing capabilities and market strategy are included as explicit sources of requirements where they are given appropriate weighing to reflect their relative importance.

ENABLER: Multirequirement tradestudy capabilities. Capability to perform trade studies across interrelated requirements (considering relative weighing) to determine and capture sensitivities.

Level D: Complete and Unambiguous Specification

Requirement definition capabilities are supplemented with an ability to communicate those requirements as unambiguous executable specifications which can be maintained throughout product development as a baseline for evaluation of product implementation options. There must be an ability to manage changes in requirements over time as views and knowledge bases change.

ENABLER: Executable specification environment. Total requirements are captured without ambiguity and is readily available for use by the team (data push). Data access is directly focused to pertinent requirements for a specific activity versus searching for pertinent requirements within the total requirements repository. The system provides the right data to the right user at the right time.

b. Schedule Types (Parallel). This category refers to the type of scheduling practices in place to support project planning and capability for simultaneous tasks.

Level A: Task-Duration-Based Schedule.

Management of schedules is done through the completion of discrete tasks. This approach was streamlined in the Henry Ford style of production lines. Tasks have clearly defined beginning and ending points. Determining percentage completion of the project and identifying schedule slippages is straight forward. Schedules are often developed by working backwards from critical dates.

ENABLER: GANTT charts.

Level B: Calendar-Based Schedule

Tasks continue to have discrete beginning and ending times but some tasks are handled in parallel. Project progress is tracked through milestones, often based on calendar points. Task completion and schedule slippages are easily determined but project completion must be estimated. Project schedules can be displayed on charts and PERT (Program Evaluation and Review Technique) programs work well in this environment. Tasks with little apparent need for intercommunication are executed in parallel.

ENABLER: PERT charts

Level C: Program-Event-Based Schedule

With broader team objectives, tasks are not discrete. Teams add value to a product based on multifunctional expertise. Individuals on teams work concurrently and often teams work concurrently. Monitoring project and task completion and identifying schedule slippage is difficult as tasks are not discrete with beginning and ending points. Tools to support project management are currently ad-hoc or nonexistent. Project tracking is based on milestones tied to project events, rather than calendar events. Estimates of task duration are based on past applicable experience.

ENABLER: Event driven program management tools. Program event-based capability that monitors the program's activities to those events and allows for total program management (event milestones) versus critical path (calendar milestones) management. Acknowledges the interrelated overlapping activities.

Level D: Continuous Addition of Value to the Enterprise.

Scheduling should be flexible depending on the project status at any given moment. New planning, project tracking and resource allocation capabilities are used to determine when to apply resource and the type of resources to apply at a given time. Project status is based on absolute assessments of remaining effort rather than percentage completion (which is meaningless in most team-oriented IPPD environments). Task duration estimates are based on rigorous analysis of the tasks and actions involved.

ENABLER: *New scheduling paradigm (model)*

c. Planning/Methodology (Adaptability). This section refers to the planning style used to plan and monitor the program.

Level A: Bottom-up Collation of Task Definition

Level A environments are characterized by a bottoms-up collection of sequential tasks. Planning is expressed as individual detailed tasks and the project plan is the collection of these detailed tasks. To be successful, all participants must be well aligned and share a common view of the project.

ENABLER: Task-management-driven planning tools. Work breakdown structure capability.

Level B: Top-Down Determination of Task Definition

An aligned view of the project is achieved through work breakdown structure methodologies. This comes from the top down and consists of frequently overlapping tasks.

ENABLER: Requirement-satisfaction-driven work-breakdown structure. Breakdown structure capability driven by requirements versus task. Require task association to satisfy requirements.

Level C: Synchronization of Concurrent, Interrelated Tasks.

Level C environments are appropriate for more complex projects where tasks are concurrent and are typically interdependent. Tasks can be specified prior to project start. Many tasks are interrelated and therefore can be conducted or performed in parallel. The interrelationship between the tasks must be known and planned accordingly.

ENABLER: Interrelated process-driven planning tools. Planning capability that acknowledges and ties interrelated tasks plus utilizes data push so that as soon as data is available, dependent tasks can be initiated immediately.

Level D: Iteratively Refined Abstract Plans.

Task identification is iteratively improved in "D" environments. Activities are initiated and are executed concurrently using abstract and estimated inputs, which are refined throughout the development cycle. Methodology is in place to ensure that the outputs of tasks are determined before they are required but the task process can be adaptable and unspecified until the results are needed without impacting the project. This is similar to the concept of just-in-time inventories of supplies or latest commitment, where slack times and task independence is exploited to focus attention only on interdependent tasks. There is synchronization of concurrent interrelated tasks. Plans emerge from top-down and bottom-up integration.

ENABLER: Environment-driven planning tools. A capability to enforce upfront data sharing starting with abstract information to derive maximum time benefit of concurrent interrelated activities and update as detailed information is available. Do not have to wait until detailed data is available.

d. Validation (Accuracy). Validation of the requirements is the process that determines if the specification meets the total requirements and if all specified processes will accomplish the intended result.

Level A: Product Specifications.

Environments termed "A" are focused on product specifications. Individual specifications are handled independently and the interrelationships of requirements are not considered.

ENABLER: Heuristic requirement fanout tracing.

Level B: Validation of Interrelated Requirements

Level B environments validate that the product meets a total set of written end use requirements that will assure customer satisfaction. The interrelationships of requirements are known and documented.

ENABLER: Heuristic interrelated requirement matrix techniques.

Level C: Validate to End User Requirements

Services, processes, and products are validated against all interrelated enterprise requirements from customers, prime contractors, subcontractors, suppliers and associated specialty groups which previously had been considered peripheral to the product.

ENABLER: Heuristic interrelated requirement matrix techniques.

Level D: Enterprise specification

Validation of requirements is expressed as customer satisfaction, where customer refers to any party who receives the result of a process. Integrated product development activities are correct by construction because satisfaction of all customers internal to the enterprise is achieved at every phase in the process.

ENABLER: Simulation of executable specification

3. Communications. Communications is the lifeblood of an enterprise. Strategies and common goals must flow out to every individual in order to mold the team into an efficient and productive unit. Feedback from knowledgeable individuals is essential to optimize design decisions and to improve the development, manufacturing, and support processes.

The concept of IPPD advocates the assembly of individuals knowledgeable about design, manufacturing and support along with customers and suppliers into a team that has complete autonomy. Design decisions which impact product life cycle cost, quality, and schedule are improved because the total enterprise is represented. This style of horizontal communication overcomes the hierarchical barriers to the exchange of timely and accurate information. The flattening of hierarchical organizations has been occurring for several years because communications have improved; vital information is accessible from easily usable data repositories; and individuals are empowered to make timely, informed decisions.

The timely exchange of accurate information is essential to rapid product cycles and cost minimization. However, it becomes increasingly difficult when team members are widely distributed, possible throughout the world. Organization studies (Allen) have shown that the effectiveness of collaboration within an office building decreases by half for every 100 feet separation between offices! Improved communication is essential to the success of IPPD.

a. Working Data Management (Control). The early phases of a program (conception and feasibility evaluation) offer the greatest opportunity to improve product life cycle cost and quality if a IPPD Methodology exists in the enterprise. An opportunity for benefits from IPPD come from the potential to eliminate the phases required for modify/optimize and redesign. Early input from down stream specialists and customer reviews of the embryonic design can result in a product which is optimally designed the first time. The forces driving design change will not be errors, but rather the injection of new technology or new lessons learned.

Level A: Local Individual Data Management

Data is managed by the creator of the data. Sharing of this data only occurs when a justifiable need generates a release of the data to the requestor. A limitation of this process is that one who needs the data must know that the data exists and who has that data. Information is characterized by individual control and availability is on a demand-pull basis. Data is often regenerated or approximated by users.

ENABLER: Workstation release control system. Data is generally input to a workstation which is maintained by an individual. The data resides in his/her workstation and is very infrequently passed on to other release control systems or to other individuals. Accessibility of data is on demand-pull as required need for information.

Level B: Data Structured for Project-Wide Sharing.

Data is structured for project-wide data sharing. The data is managed by the team and it is generally available to all organizations which are closely related to the development team. Data which is generated by the most knowledgeable source is generally available when needed. Team members know where and how to retrieve the data that they need to make optimum trade-offs.

ENABLER: Configuration management of data. Here the information that has been captured on the engineering workstation is available for project-wide data sharing. This data is maintained in a controlled configurable fashion easily accessible and retrievable to all organizations. Networking of data begins to be implemented.

Level C: Program Repository of Data

Managed data is pushed to the users that need the information. The most knowledgeable generator of data transmits the information to all key members of the enterprise that might be impacted by the information. An enterprise has the adaptability to deal with constantly changing (but managed) data and continuously improving processes. The greatest value of data sharing is realized at the earliest stages of a design, but those in the enterprise who receive this data must understand that it is fluid and changing. Early access to preliminary data carries risks, but in an effective IPPD environment the benefits outweigh these risks.

ENABLER: Central program data base with automatic notification by agents. Data that has been captured on the workstation is downloaded to a server or other computer repository that allows the data to be accessed as needed. This data can be manipulated and translated to allow optimum trade-offs. A central data base is used for storage of information.

Level D: Enterprise Data Repository

A repository of all data which is relevant to the enterprise exists. This repository allows for the data to be managed and is accessible by everyone in the enterprise. Where a team spirit exists and an IPPD mentality pervades the enterprise, there is little harm from the misapplication of this data. Information overload can occur unless there are appropriate data management systems in place with efficient and accurate interpretation of queries. The best form of dissemination is through a communications manager which reasons about the state of a design and the objectives of each team member so that the appropriate data is automatically sent to the appropriate team member when it is needed.

ENABLER: Extensible data base. Data that has been captured on the workstation is downloaded to a server or other computer repository that allows data sharing by all the team members.

b. Data Acquisition and Sharing (Accessibility). For IPPD to be successful, data must be available to be shared across the team. The basic concept is to enter data once and use it many times. The data consists of working data and released data directly applicable to the product under development as well as associated with the product. This data sharing requirements is applicable to all program phases. Another factor is that data must be usable by the requestor so data formats and user views are extremely important. For working data to be useful, certain levels of data management are necessary.

Level A: On Demand Data Pull

The needing user must request the data before a task can be performed. Translating or revamping of the data may be necessary.

ENABLER: Networked workstations with file management.

Level B: Data Available as Generated with Program-Wide Sharing.

The data is made available via notification that the data is ready for wider use. Data needed by the overall program is generated by the most knowledgeable source. Program data sharing is possible.

ENABLER: Network communication.

Level C: As-Generated Data Push

The data is available for use without request. Needed data is stored in predetermined locations to be used as needed.

ENABLER: Central data base storage on program network.

Level D: Enterprise-Wide Availability of Data

Data needs external to the program/company are satisfied. Data is available to noncompany employees with a pre-established need. Data is readily available as with internal personnel.

ENABLER: Central data base storage on enterprise network.

c. Lessons Learned Feedback (Experience).

The IPPD methodology states that designs should be influenced by downstream requirements. One of the most valuable sources of data is lessons learned from previous programs (those who ignore history are doomed to repeat it). Lessons learned are rarely used in current enterprises because they are not captured in usable form or if they are captured, designers are not aware of them or cannot readily access them. The best source of this information is experienced individuals but the rapid turnover in many organizations results in a highly volatile corporate memory.

Level A: Design Guides with Rationale and Intent

In its elementary form, lessons learned exist as design rules or handbooks. These are of little use unless they contain the rationale behind the guidelines. As guidelines have proliferated, they overconstrain the designer who is faced with many tradeoffs which will violate one or more guidelines. Choices cannot be made unless the rationale behind the guidelines is thoroughly understood. The rationale for each design rule must be available to the design team.

ENABLER: Rule Checking with structured query capability. The designer maintains information on lessons learned applicable to his/her experience. The designer has set up rules and checking devices for his/her own needs or has established manageable files to support his/her needs.

Level B: Consolidated Design Guide

Consolidated design rules or guidelines attempt to resolve the conflicts between disciplines and they provide a mechanism to optimally relax the appropriate constraints when conflict occurs.

ENABLER: Checking with structured query capability, increasingly integrated rules. Lessons learned are captured in a computer data base with a structured format. This information can be queried by the team to gain insight on his/her concerns. The information is beginning to become increasingly integrated with guides and rules.

Level C: Rationale/Weighing for Each Product Development Rule.

Weighing is added to design guides and rules to aid in conflict resolution. Rationale for each rule is captured so its applicability is known.

ENABLER: Checking with unstructured query capability with impact weighting. The information that is resident in the computer can be queried to obtain the results from lessons learned. The information has been captured and can now be addressed for its design impact and weighed for its usefulness/applicability, and is weighted to aid in proper decision making.

Level D: Dynamic Lessons-Learned Feedback

There is dynamic feedback of real-time events. As each element of the enterprise performs their portion of the design synthesis and analysis, they are able to immediately provide information to others in the enterprise so that their decisions will be based upon the current collective thinking of the team.

ENABLER: Checking with unstructured query capability and impact assessment: real-time update of lessons. The information that is resident in the computer can be queried to obtain the results from lessons learned. The information is kept current (near real-time) as are the associated design rules.

d. Decision Traceability (Legacy). A perspective to lessons learned is to understand why design decisions were made. In any design process the designer is faced with a bewildering array of tradeoffs and decisions on a daily basis. Many times a designer has a particularly important reason for specifying a particular component in a design but the design intent is rarely understood by others in the enterprise. After the design passes out of design control, modifications and changes are frequently made which prove to have an adverse affect on the product. This can be avoided if the designer's intent behind each decision is captured and retained. Continuous improvement of products and processes also requires that decisions be documented to prevent shortsighted modifications.

Level A: Individual Decision Rationale Ownership

The rationale behind design decisions is captured in engineering notebooks. However, the information is rarely known to anyone other than the designer and the design team. This valuable information is very useful to others in the enterprise but is accessible only to the extent that they can talk to the design team about their decisions.

ENABLER: Repository with structured keyword search.

The designer has generally captured his/her design in the computerized engineering notebook. He/she has annotated many of his/her design decisions in this book but are available to only himself/herself. He/she may have a simple rudimentary keyword search for this notebook.

Level B: Project Decision Rationale Ownership

Many of the lessons learned and the rationale for design decisions are applicable to many programs, however, this information rarely crosses the boundary from one project to another. The rationale behind decisions is generally available between projects.

ENABLER: Repository with unstructured keyword search. The designer has captured his/her design within the computer data base. He/she has entered the data necessary to his/her design and includes his/her comments and his/her decisions. Many of the lessons learned can now be exercised.

Keywords can now be used to search out different design information.

Level C: Program Decision Rationale Ownership

The ownership of all decision rationale and the audit trail of decisions exists at the program level. Whenever alternatives are considered, the best knowledge of all design tradeoffs is available to each member of the team. Decisions are often made based on experience, emotion and gut feel of knowledgeable experts. Capturing this knowledge from experts (knowledge mining) is a difficult but necessary process.

ENABLER: Repository with keyword search. The best knowledge of all design tradeoffs has been captured in the computer data base. Lessons learned have been fed back based on experiences, and knowledgeable experts. This information can now be exercised through a keyword search where it can be processed in a traceable manner.

Level D: Enterprise Decision Rationale Ownership

Design intent, the rationale behind decisions, and the traceability of decisions is available throughout the enterprise.

ENABLER: Repository with unstructured keyword search. All the necessary resources to give the intent and rationale behind the decisions that were made have been pulled together. Also, we have the traceability through the computer data base for keyword search. Information is readily available to make traceable decisions backed by a repository of relevant expert information.

e. Interpersonal (Equality). This is the most important of all the dimensions of communication. The metric chosen to describe this dimension is equality. Communication can be impeded by personalities and egos. As communications capability in the organization matures, there is a wider dissemination of relevant information to all members of the enterprise and they receive equal treatment with regard to their need for information.

Level A: Personality-Dependent Decisions with Organizational Agenda.

Communication effectiveness depends greatly upon the ability to receive Timely answers to questions. Telephones are extremely effective if one knows who to call and if you call at a time when the person with the information is available and has time to answer your question. Electronic mail, voice mail, and fax machines have augmented the telephone and provided improved accuracy and allowed a time shift between the question and the answer. Limitations at level A are that the questioner does not know the person with the most knowledgeable answer and the questioner does not know how to ask the right question in a foreign field.

ENABLER: Electronic communication. At this level the most basic communication instruments are implemented. The telephone perhaps being the most widely used instrument to disseminate information and communication. Voice mail and fax machines are filling a large job. Work stations are beginning to be used extensively.

Level B: Team Perspective

The enterprise provides a capability for a questioner to query the entire spectrum of experts without knowing specifically who they are. This is often referred to as a "broadcast." Anyone in the enterprise who has information to contribute to the questioner can respond. This greatly improves the ability to obtain data from the most knowledgeable person, but there is no assurance that the expert will respond, even if he receives the question. Also, there is no assurance that the questioner will respect the advice if he does not know the responder or questions his/her credibility.

ENABLER: Multiple views (jargon-to-jargon translator). Workstations are becoming a necessity rather than a nicety. The information that is entered now is integrated with data obtained from the most knowledgeable people and is disseminated throughout the enterprise using the communication media mentioned in Level A.

Level C: Equal Input/Impact.

The specialty engineering advisors are elevated to the level of expertise and respect accorded to design experts; they are equal partners in the team. Communication flows freely, many people review the questions and responses, and consensus support is developed for optimum decision making.

ENABLER: Knowledge-based cross-discipline advisors. Data is entered into the data base from the experts. Being equal partners at the levels of expertise communication flows freely. Computer bulletin boards, jargon-to-jargon translation, and multiple design views are harmonious. Knowledge-based cross-disciplines are achievable.

Level D: Knowledge-Based Perspective

The design process (i.e., the designer's workstation) provides on-line design advisors with automatic conflict resolution. The designer can communicate with these expert systems through natural language queries. All members of the design team care about one another and the mutual success of the team. There is a shared intimacy throughout the enterprise (which may span global locations) that is supportive and nonthreatening.

ENABLER: Knowledge-based generative tools. The designer is able to access the computer data base to provide areas of automatic conflict resolution. The designer is able to communicate with these experts who have entered their knowledge-based information into the computer data base. The designers are able to intimately resolve areas of conflict by using the shared expert information.

4. Product Development Methodology. The product development methodology must be understood by all and must encompass everyone affected by the process. The process must be predetermined, documented, and followed. The interaction of people, the interrelationships of tasks, and the timeliness of data must be comprehended. The capture of total requirements, the total product development process, the design of the manufacturing process, and the design of the product support processes are all included within the product development methodology.

a. Optimization (Customer Satisfaction). The primary goal of the organization is to deliver a product with the lowest cost, the shortest schedule, and the highest quality which results in customer satisfaction. Optimization of the product during the development cycle consists of many factors. Of extreme importance is early tradeoffs among the functional disciplines to avoid suboptimization at the expense of another functional area. The product should be viewed for producibility, testability, reliability, maintainability, etc. Each of these areas must be examined to improve the robustness of the product when considering the manufacture and customer usage of the product. As we move closer to the right side of the matrix, we increase the customer satisfaction since a more complete enterprise team is involved in key product decisions.

Level A: Review-Based Optimization

Individual disciplines optimize their areas through a series of lessons learned checklists, formal optimization methods, and expert review. Conflict is resolved at scheduled multidiscipline design reviews later on in the project cycle. Given a complete and correct set of design guides supported by an adequate level of expertise in each discipline this process can result in acceptable designs and good customer acceptance. However, since conflict resolution happens serially, some suboptimization will occur, resulting in a longer schedule due to redesign activities addressing problem areas.

ENABLER: Single requirement optimization. Each discipline utilizes a discipline-specific tool for optimization of a portion of the design per its area of expertise. Design constraints/requirements from other disciplines or the customer are considered in design reviews later in the design cycle.

Level B: Limited Interrelated Requirement Optimization.

Multidiscipline awareness results in consolidated lessons learned design guides with some automated checking. Cross-discipline optimization of specific product attributes takes place during design. Multilevel (e.g., component vs assembly) optimization supported by specific tools is conducted. The team conducts trade-off activities with respect to all disciplines in the early concept phases, thereby achieving a level of overall product optimization in the early concept phases, avoiding redesign later.

ENABLER: Multiple requirement optimization. This level interfaces discipline-specific CAE/CAD software tools so that output from one tool can be automatically input to another tool. New simulation and analysis tools have some inter- discipline cross-fertilization capability for design verification earlier in the design cycle.

Level C: Programwide Requirement Optimization.

Product optimization addresses multiple program requirements in a true team environment. Early broad scale (horizontal) trade-offs between design, manufacturing, and operational processes are supplemented with direct advice from customers and suppliers. Vertical optimization across many levels of product definition takes place. The central data base, with its unified data model, is an asset in making these decisions. Included in this data base is a knowledge based cross-discipline advisor as a decision support system.

ENABLER: Multiple requirements optimization. Multiple requirement optimization tools are integrated closely with a single data base such that when each discipline is considered in a portion of the design, most other discipline design constraints and requirements are visible and available for early design trade-off decisions. Specialty design requirements knowledge is captured in the data base for all to consider early in their respective design responsibilities.

Level D: Total Weighted Requirement Optimization.

Global optimization (combined horizontal and vertical) occurs addressing all requirements. The enterprisewide team includes the customer and key suppliers to effectively make early trade-off decisions. With the customer involved, the requirements assessment can be optimized to satisfy the customer without overdesign. The supplier involvement helps in making design solutions compatible with supplier's process capabilities. This product development process results in the highest level of customer satisfaction for the lowest cost and schedule when dealing with high product complexity and technology.

ENABLER: Weighted multirequirement optimization. Each discipline accesses a fully interactive tools set and data base where each design requirement, constraint, and verification entered into the data base ripples across all discipline views of the data base. Decision support tools help to weight the various design details and options with some automatic decision capability.

b. Data Libraries (Consistency). Data libraries consist of that set of data which is needed to design, analyze, produce, and test the product. It is assumed that there will be a single master library source coordinating all of the various discipline libraries.

Level A: Control of Preferred Parts and Process Libraries.

We have a well maintained set of standard parts and process libraries along with associated design guidelines. The libraries are representative of individual disciplines. Static discipline-dependent design rule libraries and standard optimization algorithms are also available. On-line library selection assistance is available for the design engineer.

ENABLER: On-line libraries, selection assistance. Many discipline-specific libraries with selection assistance exist that cover electrical components, component thermal characteristics, materials, processes, electrical models, reliability models, etc. These are usually independent of each other and independently maintained.

Level B: Controlled Libraries and Reusable Modules and Intent.

Libraries are integrated into modular packages that include multidiscipline information for standard parts or higher-level reusable assemblies. Reusable product modules are vertically integrated to include design intent at multiple levels of design and critical design constraints. Designs stored in these libraries are proven, qualified, and reusable; they include supporting documentation. Reusable process modules include optimization criteria and constraints. Libraries of past product/process optimization experimentation efforts facilitate rapid future improvement.

ENABLER: Program-accessible networked library. Fully electronically documented proven product and process module libraries are available to reduce "reinventing the wheel" on portions of new product designs. New projects can access these design intent modules along with data, process, and optimization libraries through a network.

Level C: Controlled Technology-Independent Libraries

The library entries are highly integrated and technology independent containing information needed for external CAE tools such as producibility, reliability, maintainability, etc. The libraries contain data linking them to decision support and optimization systems to supply optimum selection assistance when considering the many multifunctional design guidelines. The design rules and optimization criteria are weighed to reflect the criticality of a rule covered across disciplines along with supporting parametric data constraints, other form of design knowledge and/or rationale. Part libraries support the views and data needs for all the disciplines on the design team.

ENABLER: Technology information external to tools. Expertise from each discipline is electronically captured and integrated with the libraries to provide optimum selection assistance with respect to weighted advice from all disciplines.

Level D: Controlled Real-Time Library Data from Source

We have a controlled real-time library from the source. This is possible because the team members are enterprise-wide including the customer and key suppliers. The team is also connected through an enterprise wide seamless computer environment allowing easy access to the data.

ENABLER: Technology information external to tools. Each discipline has a tool to update in read time their own area of the library and library advisor subject to some library control group approval.

Changes are immediately available to all team members.

c. Development Process (Controllability). Until product development is viewed as a process, it will be extremely difficult to begin the journey of continuous improvement. The development process must be controllable and measurable to be completely understood and for process optimization to occur. For this discussion, we will define the development process as all of the activities that occur during the program execution, which when properly performed, will efficiently place the desired product into production. This process includes all disciplines and initiates at program conception and concludes at the release to manufacturing (make) process. Included is the development of the product support/operational support process and the design of the manufacturing processes. The key to process management is to identify the steps needed for improvement and the sequence by which to improve them.

Level A: Product-Independent Repeatable and Consistent Process.

The product development process is consistent and repeatable. Standard methods and practices are used for managing the stages of design activities. Subprocesses are modeled within specific disciplines using standard techniques. This process is independent of the product. The interrelationships of requirements among disciplines are not fully understood since the teams are primarily formed along functional lines. The output is only as good as the individuals and their understanding of the process.

ENABLER: Consistent process methodology enforcement. The order of process activities is enforced through a framework of process models and standard methods.

Level B: Measurement Standards Definition

The basic process structure is established with dedicated resources assigned. Critical parts of the process are modeled in detail such that hardware, software, test and manufacturing processes supply deliverables which meet the requirements of their internal and external customers and eliminate non-value-added activities. Interrelationships among critical attributes of processes or between product success criteria and development processes are identified in a standard manner. Extensive process optimization experimentation is supported by measurement standards defined for critical process parameters.

ENABLER: Key process parameter identification tools. Critical process steps and associated product/process parameters are identified in a systematic manner using extensions of the capabilities provided in level A.

Level C: Closed-Loop Control

Operating decisions are based on quantitative process data resulting from extensive analysis and simulation of critical process activities. Process models are highly integrated to include the entire enterprise with discrete inputs from customer and suppliers. There is significant organizational learning resulting from the multidisciplined team study of the process. Process interactions are well understood (quantitatively) and achieve closed-loop control over the end-to-end development process. In order to be effective, significant discipline is required to track and eliminate enterprise process problems.

ENABLER: Integrated process methodology. A total program or enterprise view is maintained by programwide networked process flow models. Individual interrelated key process parameters are supplied by simulation or experimentation.

Level D: Process Improvement and Optimization

The process is understood with a high degree of control achieved. The major focus is on improving and optimizing the enterprise process operations. The customers' and suppliers' processes are an integral part of the enterprise. With these two critical elements, significant non-valued-added activities and product functions are eliminated due to the excellent real-time team communications and explicit quantitative understanding of process interactions. Another feature of this level is the continuous flexible optimization of the process to improve the product.

ENABLER: Integrated process optimization. Enterprisewide networked process flow with the status supplied from the individual interrelated key process parameters for a total enterprise view.

d. Reviews (noninterruptive). One of the most glaring problems in current product development methodologies is the inadequacy of design reviews. There are many reasons for this - some of which are: organizational, human behavior, market changes, and critical resource skills. Many product field failures can be attributed to lack of proper and complete design reviews. The goal of the highly effective organization is to standardize the review criteria and strive for a condition where conflicts are resolved quickly and the design is correct by construction.

Level A: Schedule-Driven Product and Process Critiques

Design reviews are schedule driven and critique the product and process. For the most part, each functional area schedules a series of reviews for their own discipline with very little consideration of cross-functional trade-offs. More often than not, this type of review is only as good as the experts conducting the review limited by the discipline-specific guidelines they use. When the design is complete, multi-discipline reviews are held but other functional areas may only have a day or two to critique the design. Review results are marginal. Multidisciplinary teams are assembled to correct specific design problems.

Level B: Event-Driven Reviews

Reviews are multidisciplined with total team participation in all phases of every review. Controlled libraries of reusable modules showing design intent provide a level of review before the fact of design as do consolidated sets of design guidelines. The multidisciplined team members have access to the data and are empowered to make design decisions without review by multiple levels of enterprise activity. The design reviews tend to be event driven, ensuring that a complete design package, rather than pieces, is reviewed.

Level C: Immediate Issue Resolution

The team actively obtains real-time input from the rest of the enterprise -- including customers and suppliers -- to help make more complete decisions. For example, purchasing may have some advice on an early component selection based on previous vendor performance. Normally, this type of data would be relayed during preliminary or critical design reviews, much too late to make design changes. So, the immediate resolution of issues on a broader perspective separates this level from the previous ones. Formal reviews are then free to concentrate on program risk areas, true unknowns, or opportunities for optimization.

Level D: Status Reporting

The design is correct by construction. Much design review is accomplished in advance by ensuring and improving the correctness of design knowledge entered into libraries. The team is autonomous and the technical content is determined continuously as the design progresses. Frequent internal status reviews ensure that the correct processes were adhered to and to plan strategies for design and process improvement rather than focusing on the details of the design.

e. Measurements (Information Content). The section on measurements refers to data collected in order to provide knowledge relevant to decision making. If you cannot measure your results, then you cannot control your process and improve your performance.

Level A: Measurement using Function-Specific Deterministic Indices.

The first level is characterized by intuition-based, "seat of the pants" management decisions, with access to discipline-specific data in summarized form. Broad generic design guides provide development process uniformity but little facility for conducting design trade-offs or optimization.

ENABLER: Information systems handle project requirements. Capability to collect and capture data pertinent to the discipline, not necessarily the program.

Level B: Measurement using Process-Related Deterministic Indices.

Information is detailed and multidisciplined, and includes measures from suppliers. The data is sufficient to determine where change is necessary.

ENABLER: Expanded information system to include process information. Capability to collect and capture data pertinent to the program.

Level C: Measurement using Heuristic Predictive Indices.

Quantifiable measures of customer satisfaction (the degree to which the external and internal customer's needs are being met by the process(es)) are defined and captured.

ENABLER: Statistical process control. Level D: Measurement using Relevant, Analytical, Interrelated Predictive Indices.

Level D reflects management of the entire enterprise using quantifiable, indisputable data. Data provides information not only about where change is necessary, but how much and in what direction.

ENABLER: Integrated enterprisewide factual data. Integrated, enterprisewide information system that allow management by fact.

f. Analysis Architecture (Hierarchical). Analysis architecture reflects on the scope, range of applicability, and level of integration of analysis and simulation, modeling or virtual prototyping methods and supporting software tools. Existing tools and methods are discipline-specific and each applies to a single product architectural level or product class. Data libraries to support the tools are embedded within them and not applicable to transfer, expansion, or change.

Level A: Single-Level Modeling, Simulation, or Virtual Prototyping.

The analysis architecture provides the capability for modeling, simulation or virtual prototyping at a single architectural level or single product requirement. Analysis and modeling, simulation or virtual ptototyping tools are flexible to support multiple disciplines as discipline-specific data is made available. Tools and libraries are decoupled, allowing rapid assimilation and growth of library data.

ENABLER: Single-level modeling, simulation or virtual prototyping and analysis tools. Modeling, simulation or virtual prototyping and analysis tools characterize performance and verify the design at a single product level such as hybrid application specific integrated circuits (ASIC), or printed circuit board (PCB).

Level B: Multilevel Modeling.

The analysis architecture provides multilevel analysis and characterization of reusable product and process modules. The results of analysis directly support optimization of various modules and of specific product/process interactions.

ENABLER: Multilevel modeling, simulation or virtual prototyping and analysis tools. Modeling, simulation or virtual prototyping and analysis perform at multiple product levels simultaneously to characterize the performance of reusable modules. Optimization among product levels is facilitated by multilevel tools which also provide parametric data for optimization with other modules.

Level C: Mixed Mode with Multiple Views

This level addresses a mixed mode, multilevel modeling, simulation or virtual prototyping and analysis environment. Optimization among multiple product levels within a product element and among several key disciplines are possible. Direct design synthesis of a single product attribute or product design level is facilitated. Modeling, simulation or virtual prototyping yields detailed data to support robust design of products and processes as well as parametric effects of process interactions.

ENABLER: Behavioral modeling with synthesis. Tools provides mixed mode modeling, simulation or virtual prototyping and analysis such as mixed digital and analog with use of behavior models. These tools provide multiple discipline views for data input, quantitative interpretation of interactions, and review of results.

Level D: Mixed-Signal, Mixed-Mode Process Modeling.

Level D provides behavioral and functional modeling of the complete system throughout the design hierarchy from conceptual level down through detailed design. Direct synthesis of many product attributes, multilevel design optimization, and trade-offs among many diverse disciplines is possible.

ENABLER: Total synthesis, modeling, simulation or virtual prototyping, and verification capture. Tools are integrated for total system hierarchical behavior and functional/operational synthesis, analysis, optimization in addition to verification of requirements.

g. Verification (Compliance). Verification is a process to determine the design of "correct." Correctness includes compliance with the total specification, a product that is producible, and that major risks are bound and can be brought under control. Verification is a continuous process that starts with total requirements derivation and continues through production and resolution of change orders. The verification process is adaptable to programmatic changes in requirements. Non-IPPD development processes rely heavily on prototype testing.

Level A: Discipline-Dependent Verification.

Verification is carried on within each discipline. Formal reviews and analysis are supported by detailed modeling, simulation or virtual prototypings that provide a high degree of confidence in product validity such that specific prototyping phases are reduced or eliminated; final verification takes place on what is essentially a production model. Manufacturing processes are verified early in the program through experimentation and modeling, simulation or virtual prototyping.

ENABLER: Complete suite of analysis tools. This level contains independent design verification tools that perform discipline specific modeling, simulation or virtual prototypings and analysis. Each discipline has access to analysis tools capable of analysis verification for compliance to requirements.

Level B: Multidiscipline Verification.

Verification takes place at higher levels of system integration with the application of reusable modules and optimization methods assuring a high degree of correctness at the detailed design level. Soft prototyping -- comprehensive system level modeling, simulation or virtual prototyping is used to verify conceptual/system design with respect to many disciplines well before the design gels and is difficult to change. Verification of design, analysis, and modeling, simulation or virtual prototyping tools and associated libraries takes on a substantial importance in the verification process.

ENABLER: Multidisciplinary analysis tools. Discipline dependent tools are interfaced such that inter- discipline dependent data are automatically passed from one tool to another such as thermal analysis results being automatically passed to circuit simulators and reliability predictors.

Level C: Team Verification

Verification is performed simultaneously with design. All team members participate in the process on an equal basis with equivalent supporting capability. There is a substantial emphasis on verification of design libraries and synthesis methods by all team members, including customers and suppliers so simultaneous verification is not hindered. Optimization procedures and results of optimization exercises are stored along with design history records and library verification history to rapidly verify engineering changes.

ENABLER: Compliance monitoring. Design verification tools are fully integrated to enable early and continuous design verification with respect to total requirements. Operational and manufacturing/test environment modeling, simulation or virtual prototyping tools are integrated with performance modeling, simulation or virtual prototyping tools for total design verification through the use of integrated data bases and libraries.

Level D: Correct by Construction

Level D yields robust products that are correct by construction. Development and manufacturing processes are robust as well meaning that variability is controlled and processes are relatively insensitive to design variations. Robust design and optimization procedures and direct design synthesis assure that the design is substantially correct with no external verification necessary. Verification becomes internalized, directed at assuring that the synthesis methods, optimization tools, and design libraries are correct and applicable to the design effort and related processes. Extensive tracing and capture of design efforts provide the ability to verify engineering changes simultaneously.

ENABLER: Compliance assistance. CAE tools allow for verification of total requirements. Interfaces from manufacturing and test modeling, simulation or virtual prototyping tools to manufacturing and test equipment and process computer processing unit's (CPU) enable controlled processes that assure correct product construction.

5. Automation (A IPPD Enabling Technology). Automation is not an essential requirement for IPPD but is definitely an enabler. The technology overlay supplied on the matrix (in the shaded sections) was developed to provide a quick technology input for each applicable matrix cell for those interested in the automation perspective. The intent was to provide an example of how automation could support each level, but not a complete solution nor a complete listing of possible solutions. It should be apparent that the automation sophistication varies with the IPPD environment. The integration of automation with the IPPD methodology will greatly enable the establishment of the needed environment. TABLE III-7 provides an IIPPD environment assessment matrix.

a. Computer-Aided Environment. This is a category of capabilities that have been automated to allow the computer to aid in task completion.

Level A. Vertically Interfaced Within Disciplines.

The primary focus is on specific analysis, modeling, simulation or virtual prototyping, and verification tools. Tools are primarily discipline-specific and product-level specific. However, data is readily shared between tools using standard data exchange languages (e.g., EDIF, VHDL).

Level B. Horizontally Interfaced Within Project.

Tools have a broader perspective and satisfy more than a single discipline's needs. Tools are oriented to optimization as well as analysis and verification. Libraries become as important as tools in the development process. Data is readily shared electronically between needed disciplines.

Level C. Integrated Program Environment.

Specific tools become less significant than the integrating infrastructure (framework) of the computer-aided environment. Frameworks provide the capability to integrate many diverse tools and data libraries. Common user interfaces give multiple discipline personnel access to a wide variety of tools. Data is readily accessible across the total program. The capability level across the program is consistent with all specialists having access to all tools and libraries. Design decision and optimization tools supplement traditional simulators.

Level D. Enterprisewide Seamless Environment

The framework concept is extended to the greater enterprise including customers and suppliers. Specific tools give way to tool shells -- generic simulators, design synthesizers, decision support, etc., -- which are customized by the overlay of application and module library information. Extensive libraries of shells are available. Library support and maintenance activities are a major investment. Data and data bases are common and readily accessible.

b. Information Systems. Information is a basic requirement to manage effectively. Data must be gathered, focused to topic of interest upon requires, and available when requested.

Level A. Historical Views.

Data is gathered by each discipline as design, analysis, or review activities are conducted. Libraries are created by team's discipline specialists as needed to support specific sets of tools.

Level B. Real-Time Views.

Data is gathered specifically for entry into libraries. Process experimentation, optimization procedures, modeling, simulation or virtual prototyping, supplier, and customer field use are all considered active sources of library data. Project data, including design details and rationale, analysis and modeling, simulation or virtual prototyping results, and review issues are available for use in near real-time.

Level C. Process Control Approaches.

Information is highly integrated with all disciplines working on a single project contributing to a common product/process model. Data is immediately available in a form that is readily usable by the discipline. Libraries and tools are integrated with the common model.

Level D. Predictive Approaches.

Level D extends level C to the entire enterprise including suppliers and customers.

c. Compatibility. Compatibility relates to the capacity to share data between/among tools and platforms within a discipline as well as across disciplines/teams.

Level A. Discipline Specific Hardware/Software (HW/SW) Functionality.

The functionality to support a discipline is generally localized to a single platform. Data transfers are discrete between specific platforms or between a platform and central repository.

Level B. Project Team HW/SW Functionality.

The project team has access to a uniform hardware and software environment such that tools and data are available on any platform. This commonality facilitates a greater sharing of data and team building of libraries.

Level C. Overlapping Capability and Functionality.

A unified automation environment provides multiuser perspectives. Data is readily available to all project team members in a form suitable to each discipline's view. Tools are readily accessible and adapted to discipline-specific needs. Overlapping capability and functionality leads to tools with broader scope.

Level D. Overlapping Capability and Functionality.

Level C is expanded to the enterprise team.

d. Documentation. The ability to capture information (from requirements to analysis data to general data) whereby it is stored, controlled, and available for sharing.

Level A. Stand-Alone/Static Data is captured and controlled but not readily available to share.

Documentation is created as electronic "paperless" deliverables on stand-alone desktop documentation systems.

Level B. On-line Documentation.

Data is available for sharing but must be explicitly requested. Network capabilities are used to provide on-line documentation access shared by all team members.

Level C. Autogeneration/Unambiguous.

Capability to not only capture the information but also to provide automated formatting of the information into the desired documentation. During the capture, the capability will identify missing and ambiguous requirements. Data is provided in the proper user view/perspective.

Level D. Unstructured Data Access/Retrieval.

Capability to do unstructured key word search to find the specific data requested and directly applicable to the question.

F. MATRIX USAGE

The assessment matrix is a tool which provides each program in an enterprise with the means of measuring the status of their IPPD environment. The assessment matrix is in two parts, an influencing dimensions matrix (TABLE III-6) and a IPPD environment matrix (TABLE III-7). The influencing dimensions matrix has nine categories:

Product Complexity
Business Relationships
Product Technology
Team Scope
Program Structure
Resource Tightness
Program Futures
Schedule Tightness
Competition

The environment matrix has four major categories which are attributes or characteristics of a IPPD program environment:

Organization
Requirements
Communication
Development Process

Each of the categories has several elements which together characterize that category. The IPPD environment matrix provides a snapshot of the present capabilities within a program. The capability needed to successfully carry out the program is determined by the nature of the program on the scale of influencing dimensions. The matrix is intended to be used as a self measurement tool. It is not intended (nor should it be used) to compare one contractor/staff/department with another. Used correctly, each program can measure where they are in the assessment matrix, where they should be by the influencing dimension matrix, and then plan on how to reach the appropriate (needed) IPPD environment for that program.

Utilizing the influencing dimensions matrix, the first objective is to establish the appropriate IPPD level of operation (A,B,C,D) based on the nature of the program as measured by the influencing dimensions. The influencing dimensions identified for a particular program will help guide the assessor to the required (should be) IPPD environment matrix level.

The next objective is to use the environment matrix to determine where your program is with respect to the categories and key elements. When you have determined your assessment level, the required actions to move the "where is" level to the "should be" level must be implemented.

In almost all cases, movement to the "should be" level will be beneficial to a program. Such movement generally requires the investment of time and resources that should be weighed against the benefits to the program and the organizational unit. Long term business plans, investment cost, implementation time, and the capacity to change the culture of the organization should be assessed against these benefits. However, the benefits of a IPPD environment should not be under estimated.

1. Evaluation Techniques. A necessary step in establishing an effective IPPD environment is to assess where the program is currently relative to its IPPD environment to where it should be. This is the underlying principle behind application of the matrix.

a. Assign the weighting factor for each of the influencing dimensions. Weighing factors should reflect the relative importance of each factor to successful completion of the program. The weighting factor approach is not critical. What is important is for you to determine the relative importance of each of these dimensions to your long term program success.

b. Determine the appropriate level within each influencing dimension. The level selected (A, B, C, or D) should reflect your assessment of how your program is influenced by each of the identified factors and therefore is a requirement for successful completion of this program. Your level selection is necessarily a subjective choice based on your evaluation of the impact or criticality on each influencing dimension on your program. Variations between levels must be resolved by your decision. You can use majority rules or weighting techniques if there are differences in the relative importance of the influencing dimensions. By whatever subjective method, a single IPPD environment level needs to be established.

c. Perform an assessment of the program. For each IPPD element within TABLE III-7, find the highest level for which all factors of that level are currently in place. Define this as your "current profile."

d. Compare current level to the appropriate level. By comparing the appropriate level, as determined in step #2, to the current level, areas for needed improvement are identified. All deficiencies should be brought up to the needed level. The IPPD environment is no better than the weakest attribute. With the required attributes established for each planned IPPD level, you can assign responsibility, set timetables, develop the necessary procedures, document plans, and measure progress toward implementing the identified changes.

2. Example. In order to aid the user in understanding how to use the assessment technique, an example is utilized. First we must put ourselves "in the shoes" of the program manager and understand his/her assignment. His/her charge is to develop the next generation of laser based modeling, simulation or virtual prototyping and training devices which are one-tenth the weight and size of the current devices and which will also allow for identification and position location of every individual in a training exercise. Some of the key product features must be--

- Light weight.
- Highly portable.
- GPS compatibility.
- Unique player identification.
- Low power consumption.
- Compatible operating system.
- Ability to grow with rapid changing technology.
- Ada software language.

From the assignment, there are also a number of requirements or needs placed on the program that drive product attributes/constraints and therefore, product requirements:

- Low risk approach that drives technology choices, design reuse, etc.
- Life cycle cost implications.
- Durability which drives the need for a reliable, testable, and producible product, etc.

There are aspects that impact the program, such as--

- Multiple products underway at various stages (concept through production phasedown).
- Short individual product life.
- Long-term production capacity, etc.

From the data provided thus far, you can already see the diversity of requirements that affect the program and the product. It should also be obvious that a lot of planning (both short and long term) is required, that timely communications will be needed, that long term capital investment will be requested, and that the individuals on the program must be focused on common goals to be successful. An IPPD environment will greatly aid this program to be successful. Evaluate this program by the criteria described in this document.

By using the influencing dimensions in TABLE III-1, the program manager must work with the developing contractor (i.e., the integrated product team) and use their combined program/product knowledge combined with company information (resources, constraints, policies, experience, etc.) to subjectively weigh each dimension's importance to the program and then the level of impact/criticality of each dimension from the low impact (A) to high impact (D). This is illustrated in TABLE III-6. Each influencing dimension will be discussed individually to provide insight into the thought process for marking the matrix.

- PRODUCT COMPLEXITY - The product design utilizes only common packaged devices that are autoinsertable into double-sided boards. Design is highly producible. ***B level.***

- PRODUCT TECHNOLOGY - The product design requires new application of existing technology. Newer product's designs will require new capabilities from core technologies. ***B level now but moving to C level.***

- PROGRAM STRUCTURE - The program staff is moderately large with the development staff in one location, government management at another location, and the production staff at another. The development staff, although at one location, is distributed since various products are at different stages of development and an integrated product development concept including the government materiel developer and user organizations are part of the integrated product and process management.
C level.

- PROGRAM FUTURES - Investment will be made in automation to facilitate manufacturing and test in production that spans product lines. Key suppliers have increased their capacity. ***C level.***

INFLUENCING DIMENSIONS	**IPPD Environment Level**			
	A	**B**	**C**	**D**
Product Complexity		x		
Product Technology		x	x	
Program Structure			x	
Program "Futures"			x	
Competition				x
Business Relationships	x	x		
Team Scope		x		
Resource Tightness	x	x		
Schedule Tightness			x	x

TABLE III-6 Example Influencing Dimensions Matrix

- COMPETITION - Competition for future production is fierce. European sources are already developing similar technology. The potential market for Foreign Military Sales (FMS) is high. ***D level.***

- BUSINESS RELATIONSHIPS - Relationships are mostly commercial transactions with subvendors, however, key suppliers are active contributors to the development staff and while government oversight will be minimal, there is a formal Partnering Agreement in place. ***B level.***

- TEAM SCOPE - Government and contractor teams work well together but manufacturing is the dominant force, however, all requirements are considered. **B level**.

- RESOURCE TIGHTNESS - Resources are not tightly constrained in the beginning since the Government Baseline Cost Estimate was well below the final adjusted contract cost estimate. However, resources are expected to tighten quickly due to strong pressure to reprogram funds. ***A level going to B level.***

- SCHEDULE TIGHTNESS - Schedule are aggressive and will get more constrained since the need for prevention of fratricide training is immediate and the need for better force-on-force training dominates budget considerations. ***C level going to D level.***

That completes the evaluation of the influencing dimensions on an individual basis. Next is the consideration of the relative importance of the dimensions to one another. If it is felt that each are equally important, then the program should have at least a B level IPPD environment. Even though the program should be at a B level now, the chart indicates that the program may need to start an improvement process. As it becomes more of an established program with a product base, several dimensions show that the program needs to be at the C level, since it is moving to a higher level of IPPD. If the dimensions associated with level C were weighted more heavily than the others, level C may be the level of IPPD needed now. Only you as the "integrated product team" can make those subjective decisions.

At this point, the matrix established the "should be" environment level for the program.

The next step is to evaluate the current environment position against the IPPD environment assessment criteria of TABLE III-3. This will help evaluate the "where you are" relative to the criteria and your "should be" IPPD environment, as shown in TABLE III-5. The process to perform the assessment is much the same as the process used on the influencing dimensions. Each major category will be discussed.

- ORGANIZATION - The majority of the team members are product oriented versus program oriented. Both the government program director and the contractor product manager were appointed by management as were all technical leaders. Manufacturing engineering are the dominant members with advice coming from other design influencing engineering disciplines. Their advice is considered and acted upon. The majority of supplier relationships are purchase order based but a few key suppliers provide advice during development. Training is primarily discipline oriented but any discipline can and is encouraged to attend. Performance awards are given to key impact individuals. Long-term investments are being made based on expected future production.

TABLE III-7: Example IPPD Environment Assessment Matrix

ATTRIBUTES OF IPPD:	A	B	C	D
ORGANIZATION				
Team Membership	X			
Team Leadership	X			
Team Member Contribution		X		
Business Interrelationships		X		
Training/Education		X		
Responsibility/Authority	X			
Management Decisions			X	
REQUIREMENTS				
Definition	X			
Schedule Types		X		
Planning/Methodology			X	
Validation				
Documentation	X			
COMMUNICATION				
Data		X		
Management/Accessibility			X	
Data Acquisition/Sharing		X		
Lessons Learned Feedback			X	
Decision Traceability			X	
Interpersonal				
DEVELOPMENT METHODOLOGY				
Optimization		X		
Data Libraries			X	
Development Process		X		
Reviews	X			
Process Measurements	X			
Analysis Architecture	X			
Verification		X		

- REQUIREMENTS - Primary requirements are documented. Periodic government/user/contractor meetings and spiral development will enhance traceability to user needs. Schedules are calendar driven - products may be released with known problems because of political pressures. This is because program obligation pressure and project sell off are critical. Planning and tasking acknowledges the interrelationships of tasks. Specifications are validated against requirements.

- COMMUNICATIONS - Product data is controlled within the program to allow data sharing upon demand. This allows lessons learned to be reviewed and their applicability determined. The program sharing of design and intention data across product projects encourages part commonality and design reuse. Design intent and major design approach/tradeoff decisions with rationale are captured and stored at the program level. All the team members are focused on the product and their project goals.

- DEVELOPMENT METHODOLOGY - The project tries to optimize its product across interrelated requirements. Data libraries have been established across the program to provide consistent application-independent data to all projects as well as complete product design data packages. The design methodology is documented and followed thereby providing a consistent approach and known analytical verifications. Since the schedules are project schedule driven, so are design reviews. Program defined engineering metrics have been defined and are measured based on the established methodology. Single level analysis are primarily conducted presently but in light of application specific integrated circuits (ASIC), two level analysis are being investigated. The verification process is very thorough and conducted from various viewpoints to assure proper performance in the user's hands.

This completes one portion of the assessment. The next step is to evaluate the status against the "should be" environment. As was indicated, most checks fell under at least the "B" environment. Of the eight items that fell under the "A" level, four are being improved presently so continue the good work. The other four areas need to be investigated and an improvement plan implemented.

If the "should be" environment was "C," a larger improvement plan would need to be implemented. In either case, the assessment highlighted what needed to be done, now make it happen.

This completes the assessment. Based on the matrix, the "where you are" and "where you should be" were determined and the explanation proves a road map to aid in the improvement planning. If there is a need to include automation in the plans, automation enablers have also been provided within the matrix and its descriptions.

G. CREATING AN ATMOSPHERE FOR IPPD ACCEPTANCE

In today's environment, teams are faced with large, complex products which require the contributions of many diverse disciplines if the team is to be successful in accomplishing its objectives. This can be likened to the group of workers faced with assembling a very large, very complex jigsaw puzzle. How can they organize themselves to do the job most efficiently?

Each worker could take some of the pieces from the pile and try to fit them together. That would be an efficient method if assembling a puzzle was like shelling peas. But it is not. The pieces are not isolated. They must be fitted together into a whole. The chance of any one worker’s collection of pieces fitting together is extremely small. Even if the group made enough copies of the pieces to give every worker the entire puzzle to attack, no one would accomplish as much alone as the group would if it could contrive a way to work together.

The best way to do the job is to allow each worker to keep track of what every other worker is doing. Let them work on putting the puzzle together in the sight of the others, so that every time a piece of it is fitted in by one worker, all the others can immediately watch out for the next step that becomes possible. That way, even though each worker acts on his/her own initiative, he/she acts to further the entire group's achievement. The group works independently together; the puzzle is assembled in the most efficient way. This is the type of environment that must be created to support development of "World Class" products. IPPD enables all the groups involved in the process of developing or delivering the product to participate independently together.

Creating the IPPD environment described in the matrix is a necessary step to be used to develop "World Class" products. The key is to institutionalize all of the procedures and practices used to design, produce, and support a product. American industry and Government must wake up and realize that at our current pace we will never realize the improvements that are possible. IPPD is one of the fundamental aspects under the TQM umbrella and should not be considered another flash-in-the-pan, temporary hype, alphabet soup, or another program. Instead, IPPD must be thought of as a mind set requiring cultural change. We must reevaluate all of our processes and procedures from customer interface to setting requirements for design encompassing all factions (i.e., design through user operations). These must be looked at as a total system and we must realize that most of our ills are created by rigid, inflexible, nonoptimum processes.

People play an important factor in our enterprise success or failure. To produce "World Class" products using IPPD methods, management must learn to empower its people. We need to distribute responsibility, decision making, and strategic thinking to every process. This will help sustain a competitive excellence over time. Management must take the leadership for change and continuous improvement. Saying we are good enough will lead to many organizations no longer being in existence.

The IPPD matrix can be used to determine what needed level the enterprise must operate at in order to successfully execute a particular program. Use of the assessment matrix for this purpose can be analogous to a manufacturing operation assessing its capability for just-in-time inventory control. In a similar way the enterprise must assess its IPPD capability to successfully produce the product that the customer needs, on time and within budget.

H. ROAD MAP FOR CHANGE

Once an organization has determined its current characteristics in terms of these IPPD attributes and has determined a desired level of IPPD capability for future programs, then it becomes necessary to plan the transition.

Evolutionary improvements alone will not necessarily achieve the desired result. Effective IPPD can only occur in organizations where there is a spirit of collaboration between all elements of the enterprise, where adversarial negotiations are replaced with collaborative teamwork to achieve common goals, and where products and processes are converging towards optimization of every aspect of customer satisfaction.

Most programs today are far from achieving this environment. Few enterprises (customer, suppliers, and employees) have been integrated into a collaborative entity with a shared common vision. Achieving this culture will require drastic changes. Barriers between organizations must be removed. Innovation, creativity, initiative, and leadership must be stimulated and rewarded in every process. The common vision must be clearly understood and religiously embraced by all. Every individual must be empowered to promote process improvement.

Most managers understand the multiplication of productivity which results from empowering their subordinates to make local decisions. Further gains can be realized in IPPD by improving the relationships between these empowered individuals. Relationships cannot be rigidly defined. They must be flexible, adaptable, and responsive. These relationships are elements of processes which are continuously strengthened to produce measurable improvement. Communication must improve. As electronic distribution and shoring of information expands throughout an organization, IPPD organizations can move toward a relatively flat hierarchy. Team members have equality.

It is recommended that organizations start at the top. Commanders and Chief Executive Officers (CEO) must revamp their organizations and set the example, day in and day out, through actions and words. The top leadership must obtain IPPD buy-in from their total management staff plus establish the right expectations. Upfront investment and long term commitment is required to realize the successes of IPPD. These commitments are similar to the changes that are being experienced in quality programs (e.g., quality is free; inspecting-out defects cost more than education programs to design-in and build-in quality).

An enterprise which has been infused with a zeal for IPPD is constantly searching for new and better approaches through shared experiences and lessons learned. These lessons are rapidly translated into better products. Customer needs, technology, and production processes are advancing rapidly. The best products will be produced to be a design methodology which can instantly release an improved product to an adaptable manufacturing process.

Today, most organizations are prevented from realizing these benefits because manufacturing and support processes are rigid. Therefore, design iterations are normally viewed as bad and are to be avoided. Clearly, iterations to correct design defects after design release must be avoided. However, iterations to incorporate a new technology, an improved component with lower cost or better reliability, or to meet a new customer need must be rapidly inserted into the product. The "lesson learned" improvements come from experience with the product in the field. Rapid product introduction, rapid learning, and rapid product improvement are keys to improved customer responsiveness.

A fundamental enabling technology for rapid product improvement is reliability. If a large inventory of spare components is required to support the product, it will be prohibitively expensive to change and expand this inventory with every design change. Products must be so reliable that spares are minimized.

Another expensive requirement that must be changed is the concept that every product in the field must be upgraded to reflect the latest design change. Such a requirement stifles rapid product improvement. Every year, automobile designs provide greater safety, more reliability, and higher performance. Could you ever afford the cost of annual retrofit to your existing automobile? Can anyone afford the cost of this expectation in any product? Lack of product reliability and requirements for field retrofit are two significant barriers to rapid lessons learned, iterative product improvement, and rapidly improving customer satisfaction which are benefits derived from IPPD.

IPPD is not a new concept. IPPD oriented companies have entrepreneurial team spirit, bringing together all of the best ideas from every member of the team, including exceptionally close relationships with key suppliers and customers. As organizations grow they tend to move away from these fundamentals. IPPD is a culture which can succeed in larger organizations, especially with the aid of new technology which enables collaboration among larger, dispersed teams. Section I explores many of the enabling tools and technologies which will enable IPPD.

I. **SUMMARY**

Cost! Schedule! Customer Satisfaction!

The success of an enterprise is determined by its ability to excel in these three measurements relative to competitors. Excellence in these areas is elusive but there are many programs in Government and Industry that provide direction. IPPD is one of the newest and has proven to yield substantial gains.

IPPD will cause continuous improvement in products and processes if everyone in the enterprise buys into the philosophy that the downstream requirements for manufacturability, testability, reliability, and supportability must be satisfied in the early conceptual stages of each new product development. As an aid to education of people throughout the enterprise, the matrix presented in this section is a valuable visual aid to understanding the significant attributes of IPPD. A matrix was established so that a spectrum of values can be assessed for each attribute.

The assessment matrix will aid project teams in determining the appropriate level of IPPD to satisfy the requirements of their program. First the influencing dimensions such as product complexity, technology, and program size are determined. Upscale dimensions demand an enterprise with higher levels of IPPD capability.

A high degree of IPPD capability does not exist in most enterprises today. Major culture changes are required to build this capability with the direction for change guided by the assessment. The assessment matrix decomposes IPPD into four major elements: organization, requirements, communication, and product development methodology. Each of these has several subtopics which were discussed in detail to provide an indepth understanding of four deferent levels of capability that may exist in an enterprise. The following caveats must be kept in mind through the assessment:

- Management must have established an atmosphere that allows IPPD concepts to be realized and to flourish.

- Cells within an environment are interrelated - baseline consistency within an environment is critical.

- Different levels of the IPPD environment as described in the matrix do not imply quality or achievement - they are appropriateness to the size, complexity and technology of the program.

- Influencing dimensions, including business aspects, affect the required environment.

- Assessment provides a "snapshot" in time of the status of an IPPD environment or the IPPD needs of a particular program phase.

- Assessment is not a SCORECARD during proposal or program evaluation.

- Assessment is not a comparison between organizations.

- Assessment is not a strategic planning tool.

- The matrix is an evaluation tool, not a program to be implemented.

- The assessment matrix is applicable to programs, not to organizations or suborganizations.

- Movement to higher levels of IPPD than is indicated will not necessarily operationally benefit this specific program's development, since the marginal operational benefit might not justify the amortized cost. However, continuous improvement needs to be a way of life.

This section has discussed the role of a IPPD environment in attaining excellence. A "World Class" enterprise has ontime delivery of the best products and services at the lowest possible cost and the most satisfied customers. An IPPD approach is a necessary but insufficient condition for excellence in production development. Excellence tends to lead to stagnation; organizations become reluctant to fix or change processes that work well. The most dangerous weapon is business today is change. Others who adopt IPPD will aim this weapon at the top enterprise leadership; they will change customer expectations, introduce superior technology, change government regulations, and improve resource management. Today, an enterprise will remain successful only if all internal processes are adaptable and poised for rapid and unexpected changes. Iterative, frequent, evolutionary changes are necessary to sustain excellence. Proactive leaders have a bias toward action and will seek opportunities to change the rules and tilt the competitive playing field in their favor.

The IPPD assessment matrix provides a tool to assess the current status and to provide guidance in selecting the opportunities to prepare an enterprise for successful execution of future programs.

The proponent of this pamphlet is the United States Army Materiel Command. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) to the Commander, HQ AMC, ATTN: AMCRD-IEC, 5001 Eisenhower Avenue, Alexandria, VA 22333-0001.

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APPENDIX A

CONCURRENT ENGINEERING (CE) STRATEGY

WHITE PAPER
6 MAY 92

G. B. LANGFORD, HQ AMC

CONCURRENT ENGINEERING STRATEGY (CE)

INTRODUCTION/BACKGROUND

The dramatic changes in the international political climate dictate a change in our approach to national defense strategy. Previously, our focus was primarily limited to large scale conflict with the Soviet Union, or its client states. This view of large scale conflict is no longer valid. Conflicts in the foreseeable future will be on a smaller scale, with shorter notice and against, as yet, unspecified components. This change in the global conflict possibilities has necessitated a restructuring of the composition of the force.

The Total Army will become a force largely based in the continental United States. It will have to be deployable on short notice to any place in the world and prepared to defeat any potential enemy. Frequently, it will operate as part of a joint, multiservice force and/or part of a coalition with allied forces. The Army will be substantially smaller and continue to rely on a strong reserve component. This smaller force must be technologically superior and logistically sustainable to deal with a wide spectrum of possible conflicts.

The significant reduction in funding available for Army acquisitions demands changes in the way we currently do business. We can no longer support the traditional practice of sequential engineering (blindly passing a project from one engineering phase to the next without functional interfaces) which results in non-integrated developments, limits trade-off considerations and inhibits best value in the acquisition process.

The Research and Development cycle time (inception of the requirement through the research and development, design and prototyping) and the Production Cycle Time (decision to produce to full scale production) must be optimized. These cycles can be made more efficient by replacing the traditional practice of sequential engineering with concurrent engineering, a totally integrated process.

The concurrent engineering concept is to optimize product design and all of its related processes, including manufacturing and support, at the onset of a project. The integration of product and process development enables an acquisition strategy that emphasizes proof of production through rapid and efficient prototyping and testing of products without the initial costs of large scale production.

Use of the concurrent engineering team concept (1) optimizes the use of simulation or virtual prototyping and modeling techniques in each engineering cycle, (2) minimizes problems in production, (3) focuses on external customer satisfaction, and (4) maximizes the reduction of operating and support costs and testing. This approach will be used for every aspect of the project to include the writing of the Acquisition Strategy through the writing of the Request for proposal (RFP).

The concurrent engineering approach also allows an open forum for review and continuous improvement of the product/process throughout the life of the product whether it is in research and development, engineering and manufacturing development, or the production and deployment cycle.

VISION

A TECHNOLOGICALLY SUPERIOR ARMY, WITH WORLD CLASS EQUIPMENT PROVIDED IN THE SHORTEST POSSIBLE TIME THROUGH STREAMLINED ENGINEERING PROCESSES, MULTI-DISCIPLINED TEAMS AND INTEGRATED DESIGN OF PRODUCTS AND PROCESSES WHILE SIMULTANEOUSLY REDUCING RESEARCH AND DEVELOPMENT AND PRODUCTION CYCLE TIMES, LOWERING PRODUCT COSTS AND IMPROVING PRODUCT QUALITY TO ENSURE THE BEST VALUE FOR BOTH OUR SOLDIERS AND THE AMERICAN TAXPAYER.

To achieve world class excellence in army materiel acquisition, several interconnected and mutually supporting strategies have been developed. These strategies reflect the multi-disciplined characteristics of life-cycle acquisition.

The CE strategy is the essential element for the enablement of the other strategies. The establishment of multi-disciplined integrated teams that are inherent in the CE concept will optimize cycle times being experienced in research and development and in production by integrating product and process designs, improve acquisition by reducing engineering changes through better acquisition strategies and RFPs which in turn will decrease operating and support costs and testing. CALS will provide the integrated data and information support to enhance CE application tools.

GOALS

The CE strategy strives to stress the importance of integration of all the processes across the life cycle of the materiel acquisition process by accomplishment of the following:

Maintain technological superiority.

Integrate user requirements from the inception of the development process through the acquisition life cycle.

Produce the highest quality solicitations and reduce unnecessary, government-imposed requirements.

Maximize the application of commercial specifications and standards.

Ensure compatibility of specifications and standards with international standards.

Improve cycle time efficiency.

Ensure all functional areas from Research, Development, Test and Evaluation through logistical sustainment are integrated early and continuously throughout the entire life cycle to add value to every product and process.

Reduce the number of design/manufacturing caused engineering changes in production.

Reduce costs of product support/sustaining engineering.

Become a World Leader in quality for all products and processes in both government and industry.

Institutionalize CE concepts into the normal way of doing business.

Make "Best Value" a way of life.

WAYS

Concurrent Engineering implementation workshops serve as the means for development of the ways to meet these goals.

Integrate User Requirements from the Inception of the Development Process Through the Acquisition Life Cycle.

Capture the "voice of the customer" by emphasizing user participation from the initial planning phase through the preparation of the RFP.

Eliminate barriers to the application of commercial specifications and standards and compatibility with international standards.

Ensure the Army Standardization community is involved in the Non-Government standards (commercial standards) development process.

Aggressively work toward harmonizing military, commercial, NATO, international and European community standards.

Improve effectiveness of the R&D and production cycles.

Establish multifunctional teams address functional requirements throughout the acquisition cycle.

Encourage use of simulation, virtual prototyping and modeling techniques in each engineering cycle.

<u>Reduce the number of design/manufacturing caused engineering changes in Production.</u>

Increase the use of prototyping in research and development, e.g., product improvement prototypes and pre-production prototypes.

Assure continual input and review by multifunctional team.

Develop manufacturing processes and products concurrently at the onset of the product.

Establish exit criteria requiring process performance as well as product performance.

<u>Reduce costs of product support/sustaining engineering.</u>

Maximize use of commercial sector technologies, specifications and standards.

Ensure value engineering Federal Acquisition Regulation clauses are included in RFPs.

Establish joint industry and government training programs.

<u>Institutionalize CE concepts into the normal way of doing business.</u>

Change policies to support CE concepts in acquisition cycle.

Use CE workshops to educate and share experiences.

This strategy is one of ten interconnected and mutually supporting strategies. These strategies address: Quality, Operating and Support Cost Reductions, Research and Development, Test and Evaluation, Computer-Aided Acquisition and Logistic Support, Concurrent Engineering, The Industrial Base, International Armaments, Education/Professional Development, and Acquisition Improvements. The integrated application of these strategies is central to successful accomplishment of the Army acquisition mission in the future.

APPENDIX B

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GLOSSARY

AMC	Army Materiel Command
ASIC	Application Specific Integrated Circuits
CAE/CAD	Computer Aided Engineering/Computer Aided Design
CALS	Continuous Acquisition Life-Cycle Support
CASE	Computer Aided System Engineering
CE	Concurrent Engineering
CEO	Corporate Executive Officer
CIM	Computer Integrated Manufacturing
CITIS	Contractor Integrated Technical Information Service
CPU	Computer Processing Unit
DOD	Department of Defense
DOX	Design of Experiments
EDA	Electronic Design Automation
EM	Electromagnetic
FMS	Foreign Military Sales
GaAs	Gallium Arsenide
HW/SW	Hardware/Software
IC	Integrated Circuit
ILS	Integrated Logistics Support
IPPD	Integrated Product and Process Development
IPPM	Integrated Product and Process Management
IPT	Integrated Product Team
MIS	Management Information Systems
NATO	North Atlantic Treaty Organization
PCB	Printed Circuit Board
PDES	Product Data Exchange using STEP
PERT	Program Evaluation and Review Technique
QFD	Quality Function Deployment
R&D	Research and Development
RDEC	Research, Development and Engineering Center
RFP	Request For Proposal
STEP	Standard for The Exchange of Product model data
STRICOM	Simulation, Training, and Instrumentation Command
TQM	Total Quality Management
TRADOC	Training and Doctrine Command
VHDL	Very High Density Logic