Integrated Product Realization is Key Theme for 1997 TEAM Activities

This edition of TEAMWORK is different from past issues. Its goal is to clearly define what we mean by Integrated Product Realization, and to show how it is accomplished. This edition presents a white paper (see page 3) that describes TEAM’s integration strategies in simple, clear terms. We understand that the concepts and terminology used are still complex, however. Therefore, we make liberal use of highlighted textblocks throughout the paper to reinforce key concepts and bottom-line messages. The rest of the text amplifies these facts for your more complete understanding. We hope that you find it informative, and we welcome your comments on how we can communicate more clearly.

The message of TEAM has changed little from its inception more than 3 years ago. However, we hope that the telling of the story has matured! The message in the beginning was that manufacturing must be addressed as a total system and that optimization of individual elements of product, process, or resource, without considering the whole, leads to inefficiencies. The total capability of the enterprise is only realized when product, process, and resources all are optimized for collective as well as individual success. From this message has emerged the TEAM product realization models, which make the concept of “integrated product realization” come alive.

The second element of the original TEAM message was, “deployment now.” We heard loudly and clearly from our partners that, even though long-term vision is needed, what is most important are tools that benefit today’s bottom line. There was also a realization that tools which provide near-term solutions, but don’t move us toward tomorrow’s successes, fall far short. Hence, the slogan emerged, “Long-term vision, near-

Circle Your Calendars for September 17 and 18
Partners Meeting to Feature Integrated Material Removal Demonstration

The Third Annual TEAM Partners meeting will be held in Oak Ridge, Tennessee on September 17 and 18. The theme of the meeting is, “Integrated Product Realization – On the Path to the Next Generation.” It will be the next step beyond the meeting last year in Livermore, California, where the concept of web-based product realization was showcased, and will focus on a new word for this year’s demo – “Integrated.” We will follow the same model as last year. An integrated product realization demonstration will be followed by breakout sessions in which participants will have a chance to look more deeply into the tools and technologies that make the system work.

The meeting will be held in the Pollard Auditorium in Oak Ridge. A block of rooms is reserved at the Garden Plaza Hotel, adjacent to the meet-

Continued on page 2...
Partners Meeting

The technical team is to be thanked for their efforts in putting together this document. Particular mention should be made of the work of Kim Cobb as the Enterprise Integration thrust area leader and lead author for this report, and the efforts of Bob Burleson, who leads the TEAM technical program.

TEAM-Related Research Agenda Being Developed for October & April 1997 Call for Proposals

Over the last few years, there has emerged a true spirit of cooperation among the federal agencies that support manufacturing programs. As a result of this cooperation, TEAM-related research topics will be a focus of the National Science Foundation’s semi-annual call for unsolicited proposals. In preparation for this call, we are developing a TEAM research agenda for distribution to members of the nation’s manufacturing technology research community. We will also conduct a relevant special topics session at the TEAM Partners Meeting in September. If you would like more information, call the program office at (423) 574-1884 or e-mail us at team@ornl.gov.

Integration

This slogan defines the TEAM migration strategies: understand where we are, understand where we want to go, and define a path that touches all of the points along the way.

This is the TEAM message. A message about enabling technologies that are shared by all, regardless of product, that fit into an “integrated product realization” environment. A message about commercial tools that come from these enabling technologies that support a growing and enriched manufacturing infrastructure. A message of “seamless manufacturing” where all of the information and materials flow without break or disconnect. The result is reduced costs, lowered risk, assured quality, preserved capability, maximized responsiveness, and true “dual use” for both commercial and defense sectors. This message had great impact on the Next-Generation Manufacturing project, and will continue to have impact as TEAM moves forward and as the NGM framework is implemented.

We hope that you will plan to attend, and that you will make a special effort to encourage your colleagues, particularly the “decision makers,” within your company, to join you. We are confident that we will be showcasing a maturing model of how manufacturing systems will work for success into the next century. TEAM partners have the opportunity for their companies to get a first-hand and hands-on look. Bring your managers, and let them share in this exciting event!

If you have any questions about the meeting, please call the TEAM program office at (423) 574-1884 or e-mail us at team@ornl.gov.

Visit the TEAM Home Page!

More information about the TEAM program is available on-line through the TEAM home page on the Worldwide Web. Our URL is:


The Home Page can be accessed using Netscape, Mosaic, or other Web browser applications. For more information, contact Kim Cobb at 423-576-1884, e-mail cli@ornl.gov.
“Understanding Integration”

An Overview of TEAM Strategies for Integrating the Product Realization Process

1. Introduction

The TEAM product realization process features the integration of product design and manufacturing groups. It consists of Concept Optimization, Design Optimization, and Execution phases. TEAM must deploy a distributed, agile environment for the TEAM product realization process, which places great demands on our ability to integrate diverse functions. This paper describes the TEAM integration concept and highlights particular integration tools that will be used in the September 1997 integrated Material Removal product vehicle demonstration.

1.1 The Product Realization Process

The TEAM product realization process (Figure 1) is driven by customer needs and input from other stakeholders (such as suppliers) to provide solutions in the form of products and services. This process is based on development and execution of a “product realization script.” The script, which is produced through close collaboration by all of the participants in the product realization process, contains all of the information needed to manufacture a product, stored in a format that is usable and readily available to all participants.

Figure 1. The TEAM Product Realization Model.
who need it – when it is needed. It also serves as a repository for all information about the product and its manufacturing process. The information in the script is optimized for performance and value by trading off critical product, process, and resource parameters during the composition phase, where the contributing stakeholders work together to develop the script. The script then becomes the “master” for creating product during the execution phase, where acquisition, allocation, fabrication, and assembly are conducted.

The product realization script is based on enterprise knowledge captured from past experience and includes information, and domain knowledge for similar products, product models, manufacturing processes, and enterprise resources. These knowledge assets are integrated through an open-architecture infrastructure that enables collaboration by different partners and interoperability of systems and tools.

**Concept Optimization** is the first step in the TEAM product realization process. This step captures the customer’s needs and desires, converts them into requirements, and translates the requirements into optimized concepts in the form of a “baseline script.” This is accomplished through an iterative process of capturing and prioritizing customer needs, defining solutions to the needs, establishing target parameters for the solutions, and analyzing and optimizing the parameters relative to design targets – in other words, determining the best solution about what will be made, how much it will cost, when it will be delivered, etc. This agreement between the customers and the providers is documented in the form of a product design and supporting information which are captured in the baseline script.

After the baseline script is in place, there is still more work to perform to create the detailed information needed to execute the manufacturing process. Detailed analyses that were not necessary to develop the initial product realization concepts must now be performed to optimize the designs of the product and its manufacturing processes. Manufacturing information that drives the factory must be created in the right format, and all of this information must be optimized for performance and cost-effectiveness. This is the **Design Optimization phase**, which translates the low-fidelity baseline script into a high-fidelity “manufacturing script.” This process involves three iterative design optimization environments: products, manufacturing processes, and enterprise resources.

The **Execution phase** implements the manufacturing script to produce tangible products. Necessary information is extracted from the manufacturing script to operate the enterprise’s manufacturing processes and deliver the desired product.

### 1.2 Workflow Models

The product realization model provides a high-level view of the strategy for product realization. However, the strategy must be tailored for specific product requirements. This is accomplished using workflow models, which are the roadmaps for success. They bring the right tools at the right time to do the right job in an integrated environment of total product and process optimization.

In the **Concept Optimization** phase, there is close interaction with the customer to capture the needs and desires and convert these into product, process, and resource requirements. For estimating and communication purposes, a parametric, feature-based solids model of the product is created to identify the requirements, materials, and features of the product that drive its manufacturability, cost, and schedule. The overall deliverable from Concept Optimization is the baseline script, which consists of the functional requirements, “first cut” solids model of the product, process, resource information, and design rationale. Figure 2 shows the workflow diagram for the Concept Optimization phase. **Remember that the goal of concept optimization is to get a “ballpark” agreement regarding customer requirements, and to gather the information to drive the product realization process. Detailed, high-fidelity decisions are deferred to the next phase in the process.**

Once customer needs are established to the point that the product’s requirements can be clearly and completely defined, the detail-level functions of producibility, process modeling, simulation, analysis, and resource planning are conducted – interoperating seamlessly and concurrently – to provide accurate assessments of cost, performance, and schedule for various product realization approaches. In this process, all options are considered in a systematic way – not just to evaluate the impact of individual operations, but to assess their interaction with all other operations. This ensures the best decisions are made. This process enables rapid tradeoff of key factors so that an optimized, validated design can be determined for the product and its design and manufacturing processes.
This is all part of the Design Optimization phase shown in Figure 3. Simulation and optimization tools take the baseline script to the next level of detail to fine-tune the best methods, materials, and processes for manufacturing execution. Once this step is complete, the manufacturing script is prepared. The manufacturing script is the total package of information required to produce the product accurately, efficiently, on time, and within budget. It consists of the solids model, operations process plans, validated part manufacturing and inspection programs, and supporting work instructions. The work instructions are further broken down into tooling and fixturing descriptions, cutting parameters (feeds, speeds, depth of cuts), setup sheets, material turning plans, operator instructions, and prints.
The **Execution phase** of the product realization process is where the information generated by the process is put to use in making product. In this phase (Figure 4), intelligent closed-loop manufacturing processes are performed with 100% assurance of a quality result. Such certainty is possible because control models are in place for each process and the parameters of each model are supplied in the manufacturing script for every product. The process control models are the result of a systematic process called deterministic manufacturing. This means that processes are characterized by defining all of their parameters, quantifying their interactions and impacts on process performance, defining cost and performance tradeoffs to define control limits, and developing monitoring and control strategies to ensure correct execution.

![Figure 4. Execution Workflow.](image)

2. Execution of the Workflow

Internet access to tools and information is a must in managing today’s distributed, virtual enterprises. Internet access provides multi-platform support that allows diverse users to participate in a distributed enterprise using their existing computer hardware, software, and networks. Therefore, the focus of TEAM integration activities for the September 1997 integrated Material Removal demonstration is the integration of this environment. The demonstration will feature implementation and execution of the integrated TEAM product realization process for a General Motors V8 engine cylinder head.

All of the complexity inherent to operation of a distributed manufacturing enterprise must be invisible to the user. The user does not care that the CAD system is running on a Unix workstation in Tucson and that the performance of a process is evaluated on a Windows NT machine in Cincinnati. All he knows is that he has a PC in his office and he needs to trade off the cost vs. performance of the product because he is committed to having a conceptual design ready for customer approval the next morning. He must have at his fingertips the tools and information needed to execute any part of the workflow and perform a task from anywhere on any piece of computer hardware.

This implies that we need an environment that integrates all the tools in a workflow that supports the concept of “attributes.” Features of this environment include:

- The tools required to execute the workflow must all work together
- All data conversions must be done in the background, without user intervention
- A common user interface (for the workflow, but not necessarily for each individual tool)
- The ability to link requirements to product attributes
- The ability to execute any part of the workflow from any location.
The user starts by defining the process and its attributes. A process is made up of a series of tasks and the transitions between the tasks.

For each task, the following information must be entered:

- Who can perform the task (based upon qualifications and access to resources)
- Inputs (may be files and/or attributes)
- Outputs (may be files and/or attributes)
- Resources to transform inputs into outputs
- Transitions to other tasks.

Once defined, the process is presented graphically to users.

Next the user must enter the requirements. Requirements are entered in a hierarchical fashion. Requirements that are entered may be updated during execution of the product realization process. Representative requirements for the GM V8 cylinder head are listed below; note that specific values are yet to be determined in some cases.

```
V8_cylinder_head_req
Customer_req
  Performance
    Horsepower (≥ 250 HP)
    Max_strain
    Max_thermal_fatigue
    Warranty
    Powertrain
    Flatness_datum_A
    Zone_flatness
Enterprise_req
  Quantity (10,000)
Reuse
  V8_fit
  Length
  Width
  Height
  Number_of_cylinders
  Existing_casting
  Existing_combustion_chamber
Manufacturing
  Material_and_mfg_cost (≤ $50)
  Machining_time (≤ 14 min)
  Cycle_time_per_part (< 60 sec)
  Flatness
```

Product attributes used to define the part must also be entered. Typical attributes include dimensions, tolerances, material types, and performance parameters such as cost and miles per gallon. It is expected that the actual attribute values will be updated throughout the product realization process as an optimal design is determined through iterative review and adjustment. Updated values may also be imported from different applications invoked to perform detail-level design tasks. Representative product attributes, captured in a hierarchical fashion, for the GM V8 cylinder head are listed below.

```
V8_cylinder_head_product
  Length
  Width
  Height
  Combustion_chamber
    Intake_passage
      D1
      D2
      Depth
      Offset1
      Offset2
  Exhaust_passage
    D1
    D2
    Depth
```

After all requirement, product, process, and user information is captured, the baseline script and manufacturing script information are available for review, revision, and subsequent execution.
3. The Framework

Integrated product realization means that all of the tools in the total manufacturing effort work together in a “seamless” fashion, where all information is available in the right form to all applications that need it. In the perfect solution, all systems and tools would comply with universally accepted standards. This is not the case today, nor is it soon likely. Therefore, we must adopt an integration framework as a “liaison” between all of the different systems and protocols. This integration framework allows our diverse tools to communicate.

Many organizations have commercial and in-house applications and databases they would like to integrate. This requires an integration framework, which is a software infrastructure (common objects, common services, and interfaces) that creates a common environment for interfacing applications in “plug and play” fashion and sharing information across different computing platforms and operating systems.

TEAM provides such an integration framework with three mechanisms: the Web Integration Manager, Web-Aided Engineering tools, and the Conceptual Design Cockpit as discussed below.

3.1 Web Integration Manager

The Web Integration Manager (WIM) is the focus of TEAM integration activities for the September 1997 integrated Material Removal demonstration, which will feature end-to-end execution of the TEAM product realization process for a GM V8 cylinder head under control of the WIM.

The WIM provides comprehensive Web-based management of requirements, product and process attributes, resources, and users as shown in Figure 5. It coordinates execution of the product realization process by providing elements of workflow and by invoking tools to perform each step in the process. The WIM is not tied to any particular process or tools. Any process, using any tools, can be modeled and managed by the WIM. For example purposes it is assumed that the defined process is the TEAM product realization process as defined by the workflow models in Section 1.

<table>
<thead>
<tr>
<th>WIMprojects</th>
<th>Projects</th>
<th>Resources</th>
<th>Products</th>
<th>Groups</th>
<th>Users</th>
<th>Mode: use</th>
</tr>
</thead>
<tbody>
<tr>
<td>proe_test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>material_removal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@demo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tycom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>burleson</td>
<td>User</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Name: Bob Burleson
- Email: burleson@llnl.gov
- Phone: 510-423-1967
- Fax: 510-423-7914
- Organization: LLNL

TEAM Technical Manager

Figure 5. Initial WIM Screen.
For the September 1997 Material Removal demonstration, TEAM has moved from the file-based integration demonstrated in March 1996 to attribute-based integration. Attribute-based integration allows requirements, product models, and process models managed by the WIM to be linked to information managed external to the WIM. For example, WIM product model information is currently linked to selected Pro/E dimensions. This enables tighter integration than is possible with file-based integration. Linkage of requirements to product and process attributes is achieved since all of the information is managed in one application. Since it is not realistic to eliminate files as a mechanism to share information between diverse applications invoked by the WIM, the WIM does provide file storage and retrieval capabilities needed to execute process tasks.

3.1.1 Initial Population of the WIM

Prior to beginning the product realization process, all information defining the process and the part must be entered into the WIM (this is true for any workflow management tool). Execution of the process can then begin under WIM control.

Requirements

The user can enter requirements directly into the WIM, which provides a logical hierarchy of requirements as shown in Figure 6. Requirements available over the Internet can be referenced into the WIM by entering the appropriate Web address (URL). It is also possible to import requirements from other requirements management tools, although this requires the integration of the WIM and each specific tool. Similarly, requirements created in the WIM can also be exported to other tools.

Requirements entered directly into the WIM may be updated during the product realization process. A sample WIM input screen for manufacturing requirements is shown in Figure 7.

![Figure 6. WIM Requirements Hierarchy.](image)

![Figure 7. WIM Input Screen for Manufacturing Requirements.](image)
Product Attributes

Product attributes are used to define the subject part. Typical attributes include dimensions, tolerances, material types, and performance features such as cost and miles per gallon. The WIM provides a hierarchical organization of product attributes as shown in Figure 8.

Like requirements, product attribute values may be entered directly into the WIM by the user as shown in Figure 9. These values may also be imported from and exported to external resources such as CAD systems. Again, this requires the integration of the WIM and the particular external resource.

Many product attribute values are updated throughout the product realization process as the design is optimized through multiple iterations. These updates may be performed directly by the user via WIM input screens. Updated values may also be imported from resources invoked to perform design tasks.

Process Attributes

A process comprises a series of tasks and the transitions between the tasks. The WIM provides a hierarchical organization of process attributes as shown in Figure 10. A sample input screen is shown in Figure 11 for the Create_Conceptual_Design process step.

User Information

Users must request access to the WIM using the Apply_For_Membership WIM service. User input includes a login username, password, and administrative information such as an e-mail address for notifications. After a user’s access request is authorized, he or she may then log in to the WIM using their username and password.
3.1.2 Execution of the Process

After requirement, product, process, and user information is captured in the WIM, the WIM can be used to coordinate and manage execution of the product realization process.

Users log in to the WIM and select the specific project to be reviewed or worked on. Requirement, product, and process information can each be reviewed in detail. A list of pending tasks the user is expected to complete is maintained based upon the completion of previous process tasks and task transitions. To participate in the process, the user selects a task from his or her list.

For each task performed in the process, the following steps occur.

- When a task is selected, all defined task inputs (files and attributes) are delivered to the user.
- The user invokes resources from the list of defined task resources and uses the resources to complete activities for the task.
- When the user indicates completion of the task, 1) all defined task outputs (files and attributes) are delivered to the WIM for use in downstream tasks; 2) pending task lists are updated based upon tasks that can now be initiated; and 3) users whose pending task lists are updated are notified that they can now initiate a task.

When the entire process is completed, the baseline script and manufacturing script information reside in the WIM and are available to the enterprise for execution.
3.2 Web-Aided Engineering

A major reality in moving from the way we do business now to the way we will do business in the future is the challenge of integrating existing “legacy” systems. In the TEAM product realization process, tools are provided to interface with systems which are not readily compatible with current-generation “open” hardware and software.

Web-Aided Engineering (WAE) integrates services with the WIM by linking WIM information to information managed by legacy systems. WAE translators, or “gateways,” provide access to the legacy systems without requiring users to have those systems loaded on their machines. WAE gateways turn legacy systems into WAE services. For the September 1997 integrated Material Removal demonstration, WAE gateways will be provided for the following tools used in the Concept Optimization phase:

<table>
<thead>
<tr>
<th>Function</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Pro/E</td>
</tr>
<tr>
<td>Stress/thermal analysis</td>
<td>Pro/Mechanica</td>
</tr>
<tr>
<td>Cost/ manufacturability</td>
<td>CostAdvantage</td>
</tr>
<tr>
<td>Optimization</td>
<td>DAKOTA</td>
</tr>
</tbody>
</table>

When a WAE gateway from the WIM is created with a “wrapper” (software that interfaces to the desired services) around the legacy system, the WIM user has access to legacy system information without having to navigate screens associated with that system. A gateway and a wrapper are both required to provide import/export of legacy system information to and from the WIM.

**WAE gateways can be created for any legacy system.** For example, WIM requirements could be linked to requirements managed by tools such as SLATE or RDD-100. WIM product attributes can also be linked to information managed by product data management and CAD systems such as Sherpa, Metaphase, CATIA, and AutoCAD. WAE gateways and wrappers are being created for the tools listed above because those tools support activities performed in the Concept Optimization phase of the Team model for Material Removal.

3.3 Conceptual Design Cockpit

Integrated product realization, with its systematic approach to manufacturing, opens the door for knowledge-based systems and automated information generation. TEAM is focusing its knowledge automation efforts, as a first step, on the Concept Optimization phase with a “cockpit” for conceptual design. The idea is that we put the customer and other stakeholders in the driver’s seat. They make choices about what they want, and then they quickly and “automatically” see the results of those choices. For example, the customer might select aluminum instead of steel for a certain part. He or she will then quickly see the resulting changes in weight, structural strength, stress levels, temperature performance, time to manufacture, tolerance capability, and cost.

While WAE services extend the back-end capabilities of the WIM, cockpits extend the front end. A cockpit is simply an interface to the WIM that enables users to easily perform some subset of process activities in an automated manner. For the September 1997 integrated Material Removal demonstration, a Conceptual Design cockpit (Figure 12) is provided to allow a single conceptual designer to perform iterative design tradeoff studies in real time using the Conceptual Design tools listed previously.

When used in tandem with WAE gateways, cockpits provide a high level of automation. Cockpits may also be created for other subsets of the process in addition to Concept Optimization.

The Conceptual Design cockpit is divided into four frames.

**Attribute hierarchy** – The left frame represents the attributes currently specified (either requirements, product, or process). Entries may be exploded or rolled up to display attributes at different levels.

**VRML** – The top center frame is the Virtual Reality Modeling Language Specification (VRML) representation of the Conceptual Design model of the product. The VRML file is generated in Pro/E and imported into the WIM under cockpit control.
Display of specified WIM information – The bottom frame contains the current WIM attribute information (requirements, product attributes, or process attributes). The information may be displayed, updated, and created in this frame.

Action buttons – The upper right frame contains buttons to invoke WAE services and display, update, and create WIM attribute information. The conceptual designer iterates through the process of updating WIM attributes, and performs analysis and optimization tasks, until an optimal conceptual design is determined. Actions taken with each button are as follows:

<table>
<thead>
<tr>
<th>Button</th>
<th>Action Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Reqts&quot;</td>
<td>Display, update, and create requirements.</td>
</tr>
<tr>
<td>&quot;Properties&quot;</td>
<td>Display, update, and create product attributes (primarily dimensions and constraints).</td>
</tr>
<tr>
<td>&quot;Process&quot;</td>
<td>Display, update, and create process attributes.</td>
</tr>
<tr>
<td>&quot;ProEs&quot;</td>
<td>Specify the location of the Pro/E application being used. This must be done prior to remotely updating the Pro/E model by selecting the Update button. The Pro/E model must be created independent of the WIM prior to being remotely updated from the cockpit.</td>
</tr>
<tr>
<td>&quot;Stress&quot;</td>
<td>Perform stress and/or thermal analysis with Pro/Mechanica based upon the current values of WIM attributes. The analysis problem must already be set up in Pro/Mechanica independent of the WIM. Analysis results are received by the WIM and reviewed by the conceptual designer. Parameter values are fed into the optimizer.</td>
</tr>
<tr>
<td>&quot;Cost&quot;</td>
<td>Perform cost and/or manufacturability analysis with CostAdvantage based on the current values of WIM attributes. The analysis problem must already be set up in CostAdvantage independent of the WIM. Analysis results are received by the WIM and reviewed by the conceptual designer. Parameter values are fed into the optimizer.</td>
</tr>
<tr>
<td>&quot;Optim&quot;</td>
<td>Perform optimization with DAKOTA using the defined optimization equations and parameter values. Results are received by the WIM and reviewed by the conceptual designer to determine if another attribute update/analysis/optimization cycle is needed.</td>
</tr>
<tr>
<td>&quot;Update&quot;</td>
<td>Remotely update (from the cockpit) the Pro/E model attributes linked to WIM attributes. A new VRML file is created in Pro/E to reflect the updated model, and this file is displayed in the top center cockpit frame.</td>
</tr>
</tbody>
</table>
4. Future Possibilities

Where do we go from here? In 1996, TEAM demonstrated use of product realization and workflow models for manufacturing. In 1997, we have added a richer toolset and integration. There is still much to do as we pursue the goal of building a rich manufacturing technology infrastructure that will serve us well into the next century.

4.1 Integration Framework - Product Realization Environment

While the WIM currently provides a solid foundation for the TEAM product realization process, it could be extended to provide tighter integration of diverse applications and databases. This level of integration will require an expanded integration framework.

Since the WIM has been developed using object-oriented techniques, it could be integrated with a framework based on the Common Object Request Broker Architecture (CORBA). One example of such a framework is the Sandia National Laboratories Product Realization Environment (PRE). Extending the WIM to be compliant with PRE will enable “plug and play” of applications that are also compliant with PRE. This will allow organizations to integrate particular applications determined by their specific needs. It will also enable PRE access to WAE services.

4.2 Commercial Object-Oriented Database

Incorporating a commercial-grade object-oriented database into the WIM would provide more robust information management as the amount of information stored in the WIM grows.

4.3 Implementing Other Processes

The WIM could be applied to processes other than the TEAM product realization process or to some subset of the TEAM process for a product vehicle that does not require the entire product realization process. This would require definition of requirement, product, process, and resource information for new processes.