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Design Through Analysis (DTA) Roadmap Vision

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Abstract

The Design through Analysis Realization Team (DART) will provide analysts with a complete toolset that reduces the time to create, generate, analyze, and manage the data generated in a computational analysis. The toolset will be both easy to learn and easy to use. The DART Roadmap Vision provides for progressive improvements that will reduce the Design through Analysis (DTA) cycle time by 90-percent over a three-year period while improving both the quality and accountability of the analyses.

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List of Acronyms

ASC	Advanced Simulation and Computing Program
APC	Analysis Project Coordinator
ASM	Analysis Solid Model
ADAPT	Advanced Design and Production Technologies
BOM	Bill of Materials
CAD	Computer-Aided Design
COTS	Commercial Off-the-Shelf
DART	Design through Analysis Realization Team
DP	Defense Programs
DTA	Design through Analysis
DSM	Design Solid Model
DSW	Directed Stockpile Work
EBOM	Electronic Bill of Materials
ESAPP	Engineering Sciences Analysis Process Plan
ESAW	Engineering Sciences Analysis Workflow
IDE	Integrated Development Environment
LAN	Local Area Network
NNSA	National Nuclear Security Administration
NWC	Nuclear Weapons Complex
PDM	Product Data Management
PMT	Process Management Team
PSE	Problem Solving Environments
SDA	Simulation Data Archiving
SDM	Simulation Data Management
SNL	Sandia National Laboratories
STS	Stockpile to Target Sequence
VIEWS	Visual Interactive Environment for Weapons Simulation

NOTE

DART is a very dynamic project that is changing daily. The details in this report reflect the state of the project at the time this document was published. Additional documents related to DART will be placed on the Sandia Web FileShare system at https://wfsprod01.sandia.gov and the Sandia Internal Web at http://dart.sandia.gov/

Executive Summary

The Design through Analysis Realization Team (DART) was assembled for the sole purpose of guiding Sandia's Design Through Analysis (DTA) activities with the goal of achieving a 90-percent reduction in the DTA cycle time while improving product quality.

This goal will be achieved by focusing on the following three core values:

- ***Reengineering of the DTA toolset***, which includes continued research and development efforts, automation of trivial, but time-consuming, processes, and removal of unnecessary procedures.

- Better ***management of metadata*** throughout the DTA process so that data is entered once and maintained thereafter.

- Ensuring that the DTA tools work together in an ***integrated environment*** for the end user, providing a single-point of access, with a flexible tool suite without gaps and non-beneficial overlaps within the tools.

A reduction in the DTA cycle time will provide Sandia weapons programs with a more responsive model-based engineering infrastructure that will allow it to better support the needs of a rapidly changing stockpile.

Implementation of the plan will be carried out through the DART Program Structure with technical improvements achieved within the four DART Program Sections[ϕ]: Information and Data Services, Tools and Infrastructure--Preprocessing, Process Integration, and Tools and Infrastructure--Postprocessing. Improvement of DTA productivity by an order of magnitude will require a very focused and well-managed program.

The DART Program must be committed to provide outstanding analysis tools and data accessibility, but a commitment from user community management and staff to employ these capabilities in their day-to-day jobs is essential. To facilitate this, DART will provide an efficient means to quick access software and hardware documentation; it will improve current documentation, develop a user knowledge base, and generate documentation for new tools and processes.

This DART Roadmap Vision provides the structure for progressive improvements in the accessibility, integration, and analysis of DTA capabilities needed by analysts. This document specifically focuses on a few of the initial, high visibility shortcomings in DTA landscape. It is expected that additional focus areas will be identified and addressed. Ultimately, the DTA improvements and integration will facilitate rapid model development and comprehensive model-based support of Stockpile Stewardship. An agile DTA infrastructure will provide the capabilities required to develop and support new Sandia initiatives.

[ϕ] Additional sections are in the process of being added.

1 Design Through Analysis Project

The focused investments of the Advanced Simulation and Computing Program (ASC) targeted toward advancing the state of Sandia National Laboratories' computational capabilities and hardware resources has greatly reduced the computational time required to perform a simulation. The increased computational capacity has also made it possible to simulate larger and more complicated systems. As a result, a greater percentage of the design through analysis (DTA) process time is spent in problem set-up and data management. To assist analysts in the development of these large complex models, ASC has funded several problem set-up, post-processing and visualization tools like *Materials WISDM*, *SIMBA*, *CUBIT*, *ParaView*, *Ensight*, *SimTracker*, and *Data Services*. Several commercial tools are also routinely used in the process. However, more complex problems coupled with the greater number of tools and the lack of integration among them has made it difficult for analysts to provide timely response to their customers and provides a greater vulnerability to error. Simply put, the tools are not being developed as an integrated and optimized solution. Although many of the tools are very capable, the lack of integration is reducing their usability.

1.1 DART Objective

DART was assembled for the sole purpose of guiding Sandia's DTA activities with the goal of achieving an order of magnitude increase in productivity while improving quality. This goal will be achieved by focusing on the three areas of:

- *Reengineering*. Reengineering of the DTA toolset includes continued research and development efforts, automation of trivial processes, and removal of unnecessary procedures.

- *Metadata Management*. Better management of metadata throughout the DTA process so that data is entered once and maintained thereafter.

- *Integration*. Ensuring that the DTA tools work together in an integrated environment for the end user, providing a single-point of access to a flexible tool suite without gaps and overlaps.

Large increases in DTA productivity will provide Sandia weapons programs with a more responsive model-based engineering infrastructure that will allow it to better support the needs of Stockpile Life Extension Programs. With the increasing role of modeling and simulation in the design and qualification of weapon systems, the definition of a seamlessly integrated DTA process is a critical element for the successful integration of ASC-developed resources into weapons engineering activities. The integrated DTA process; however, is not limited solely to weapon-related analyses and will benefit all computational simulation programs.

1.2 DART Vision

DART's vision is to provide analysts with:

- A robust, capable set of tools, both commercial and in-house, that will

provide assistance in the various phases of the DTA process, including project planning, meshing, model building, model management, simulation status tracking, job submission, and archiving.

  - The set of tools will be comprehensive and coordinated providing easy transitions from one to the other.

  - The tools will work together in an integrated fashion presenting to the user a common and shared work environment.

  - The tools will handle the rigorous demands from Sandia analysts including heroic size problems, high levels of automation, ability to be controlled at fine levels of detail, and be designed for use in a distributed heterogeneous computing environment.

- Seamless management of metadata to ensure that data is preserved throughout the DTA process to eliminate redundant and often inaccurate and error-prone reentry of the data. The metadata format and interfaces will be application-neutral to facilitate the addition of new applications and tools to the toolset.

- A user environment that seamlessly integrates the DTA tools for setting up and performing modeling and simulation studies, and for supporting all stages of the Engineering Science Analysis Process [1,2,3].

- An integrated archival system storing models and simulation studies to facilitate data retention requirements and model reuse and sharing.

- A support and documentation infrastructure that will provide efficient access to both tools and their documentation.

Ultimately, the DTA improvements and integration will facilitate rapid model development and comprehensive model-based support of Stockpile Stewardship. NWC decision makers need this for Annual Assessment Reports, retrofit and Life Extension Program decisions, and programmatic and funding priority decisions. In the future, a mature DTA infrastructure will provide the capabilities required to support new Sandia initiatives like the Rapid Small Build weapon development efforts.

1.3 DTA Business Drivers

One of the major guiding principles of the establishment of DART is the enhancement of Sandia's ability to support the National Nuclear Security Administration (NNSA) strategic mission and its mission objectives. Several business drivers for DART may be directly derived from this principle. The enhanced DTA infrastructure provided by the DART Program will:

- Reduce the DTA cycle time and improve product quality, allowing Sandia to more successfully migrate ASC-developed resources into the design and qualification of weapon systems.

- Move Sandia to a virtual product design environment by allowing the simulations to impact designs early on in the process. This eventually will lead to the minimization of prototyping and testing thereby helping to reduce both cost and time.

- Facilitate an effective, efficient model-based engineering infrastructure, enabling Sandia to better support new NNSA initiatives like rapid small build nuclear weapons development.

- Promote flexibility of the nation's stockpile by maintaining the relationships of the various model artifacts and metadata to each other and to weapon system requirements for which they were performed. This will allow Sandia to preserve the model-centric qualification strategy of a weapon system and reapply that strategy to the rapidly changing requirements of an ever-decreasing stockpile.

1.4 Design Through Analysis Toolset and Infrastructure

Historically, the infrastructure encompassed by DART has not been considered a distinct program, but rather a collection of individual development, improvement, and maintenance programs under ASC PSE, VIEWS, DisCom and Advanced Application Development. This resulted in a conglomeration of tools which were not integrated, easy-to-use, nor widely distributed. Additionally, due to lack of oversight of the entire process, gaps and non-beneficial overlaps exist among the tools.

From the analyst's perspective, there are too many tools and they are not integrated. Analysts are required to find, install, and maintain each of these tools as well as self-train in their use. Furthermore, analysts must manage the interfaces and data exchanges between these tools. For example, to specify material properties for a simulation, first the material specifications must be determined and associated to the element blocks in the mesh (of which there may be hundreds). The properties for that material must then be located, either from a handbook or a material properties database. The properties must then be entered manually into the correct fields in the model builder or text editor.

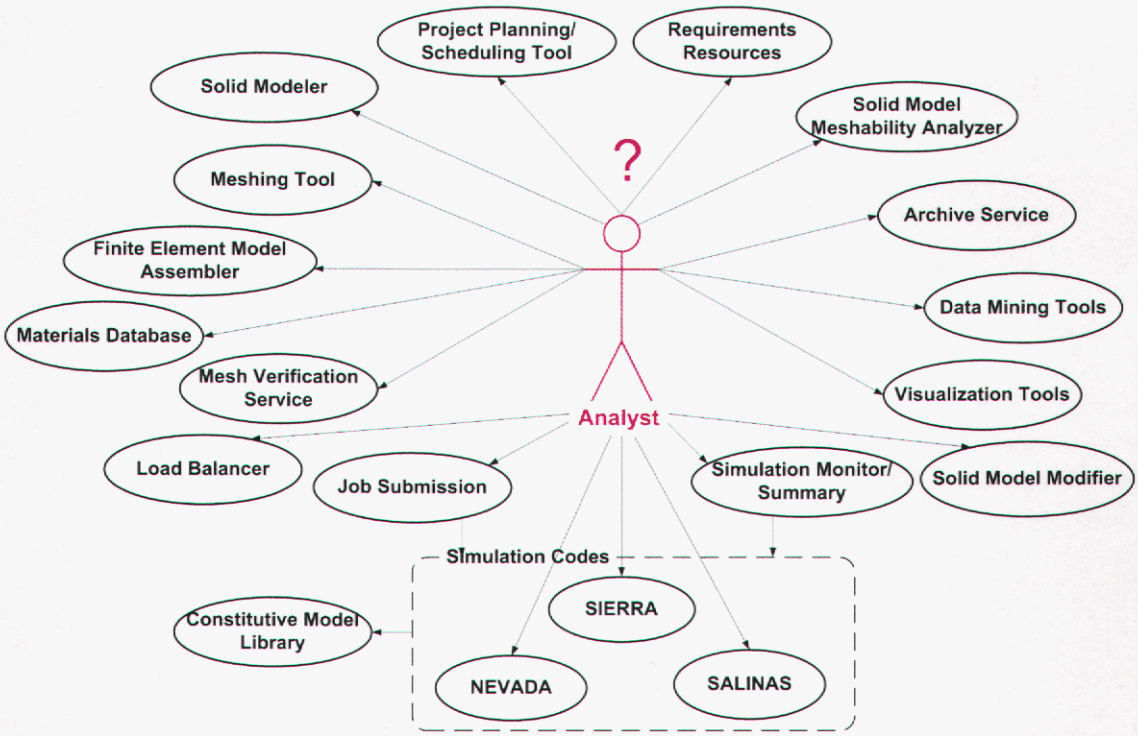

Figure 1-1. Historic State of the DTA Environment

In the target future state shown in Figure 1-2, analysts will have a single point of access to all tools and these integrated tools will work collaboratively to streamline the DTA process. The integrated environment, called hereafter the Analysis Process Coordinator (APC), together with a strong metadata infrastructure will automatically maintain associations between model components, material specifications, and material properties. Manual re-entering of data should be eliminated or very much reduced. Additionally, the DTA tools will be well supported through a coordinated support infrastructure and well documented through a central web portal called the Analysts' Home Page (AHP).

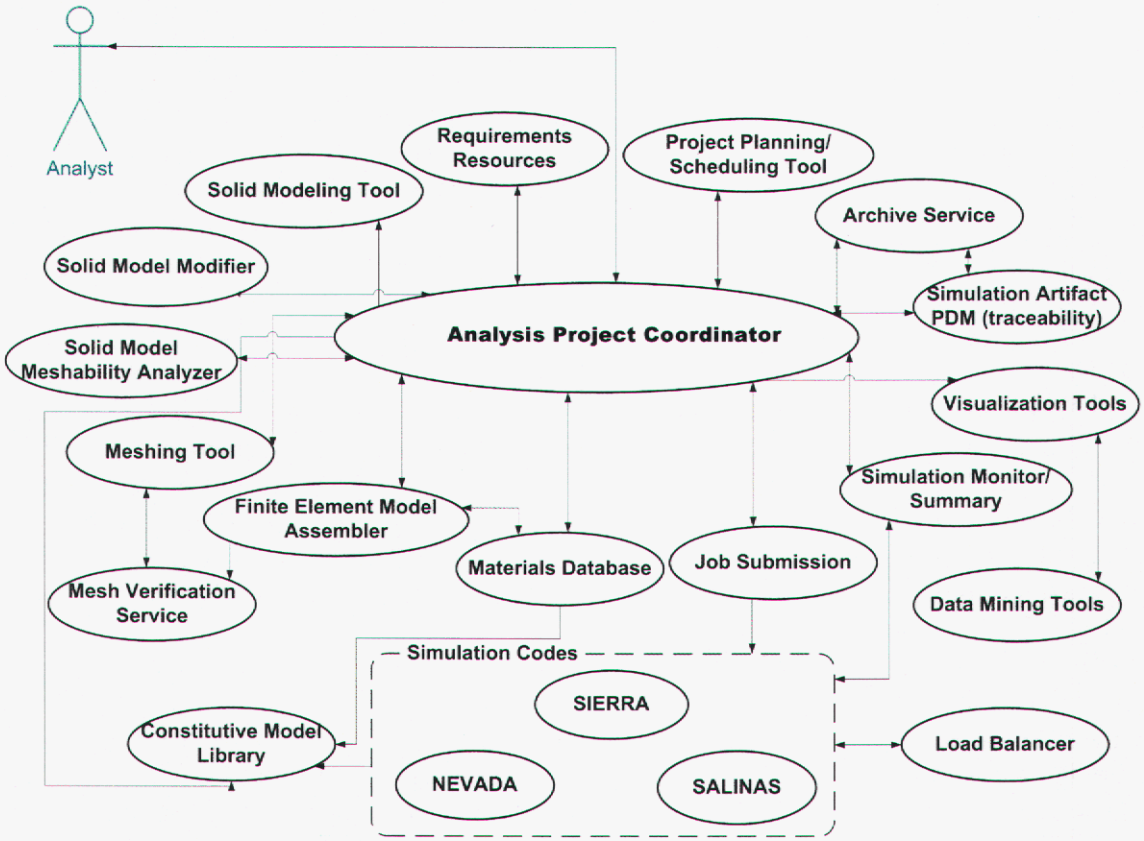

Figure 1-2. Future State of the DTA Environment illustrating the integrating role of the Analysis Project Coordinator

1.5 DART Program Sections

The need to manage DTA as a distinct entity became apparent as the vision established the magnitude and scope of infrastructure improvements necessary. Initial analyses by the DART team identified potential for impact in four main areas:

1. ***Information and Data Services***. This section will focus on managing metadata generated and used through each step of the DTA process. This will require the design and implementation of a metadata management scheme that allows analysts to enter data once. This scheme will enable persistence of metadata for downstream operations and support reuse in subsequent DTA process cycles, and provide version control and tracking. This section is also in charge of developing a Simulation Data Management (SDM) system to facilitate more global access to simulation data based on Need-To-Know qualifications, as well as medium and long-term archival solutions.

2. ***Tools and Infrastructure--Preprocessing***. This section will focus on geometry manipulation, mesh generation, load balancing, and input file creation including specifications of loads, boundary conditions, and material properties. The section will strive to eliminate the gaps and overlaps between existing tools in the process, improve integration and sharing between the tools, and eliminate or reduce the time spent in each individual tool by improving the core process of each tool.

3. ***Process Integration.*** This section includes the development of a single-point of entry for the DTA tools through an Analysis Project Coordinator (APC). The APC is responsible for integrating with the SDM and other DTA tools. This section is responsible for developing the Engineering Sciences Analysis Workflow (ESAW) and is also responsible for developing an Analysis Home Page (AHP) where "tribal knowledge" of the DTA process can be readily available to analysts and provides a platform for both DTA tools and analysis tools to broadcast news and updates to the community. Benchmarking for the entire DTA process to measure both impact of the DTA Program and identification of bottlenecks is also an important project within this section.

4. ***Tools and Infrastructure--Postprocessing.*** This section will focus on analyzing, visualizing, understanding, comparing, investigating, and discovering the results produced by computational simulations. It will ensure that the entire breadth of post-processing tools will be provided either through commercial or in-house developed software packages. It will ensure that the tools in this area are integrated and work with other tools in the DTA process.

The DART Program must provide outstanding analysis tools and data accessibility, but a commitment from the user community management and staff to employ these capabilities in their day-to-day jobs is essential. Institutionalization of a formalized analysis process is being established through the Engineering Science Analysis Process Plan [1]. Within that process; however, the user community will be able to choose the best tool for the specific task. Furthermore, key to the success of DTA is the role that the individual tools play in the process.

This DART Roadmap Vision provides the structure for progressive improvements in the accessibility, integration, and analysis of DTA capabilities needed by weapon system analysts.

1.6 Design Through Analysis Leadership Structure

The corporate *DTA Owner* appoints the *DART Project Leader* who works under the *DTA Leadership Team* composed of Sandia Level II managers from the various line organizations responsible for DTA. The *DART Project Leader* works with the *Oversight Committee*, the *Roadmap Committee*, and the *Section Managers* and works with *Funding Sponsors* to ensure that there is adequate funding for all initiatives.

1.6.1 DTA Corporate Sponsor

The corporate sponsor is a center director who is tasked with the corporate oversight of the design through analysis process at the laboratory. He will provide necessary leadership and visibility as he champions the DTA efforts on a corporate level, particularly within the program elements and directors aligned with this effort. He will also provide support in acquiring and maintaining the needed funding for the project.

1.6.2 DTA Leadership Team

The leadership team will provide support for DTA activities by providing additional vision, management support and progress monitoring. Continued input on the directions

and progress necessary to achieve results will be provided informally or formally as often as needed to ensure continued and proper focus of the effort. Management support will be provided as needed in establishing trust in the stake holders, helping to identify and overcome barriers in the culture and in the corporate systems, offering operational suggestions and modifications, and providing any useful contacts and advice. The leadership team will also periodically review progress and suggest course corrections as deemed appropriate. These reviews are envisioned to be informal and ongoing.

1.6.3 Funding Sponsors

The funding sponsors will provide funding and needed oversight dictated by the funding programs. Formal requirements will be gathered and incorporated into the project plans and roadmap as described below. Of particular importance is the ASC funding, with Mike Koszykowski providing a critical role as the ASC management team DTA representative. It is anticipated that important changes in *direction* and *prioritization* of development activities may occur as the roadmap is instantiated and executed. However, it is not anticipated that funding *levels* for the impacted organizations will be significantly affected.

1.6.4 DTA Project Lead

The DTA project lead is responsible for organizing and executing the DTA project efforts. The project structure and management process must be designed and implemented by the project lead. This structure should provide a strong integration amongst all DTA efforts and ensure a continued ownership and participation by the analyst and design communities. Specific duties include the following:

1) **Roadmap Generation**. The project lead must ensure that a detailed roadmap is generated, followed and updated as needed to provide the guidance needed in DTA. He should ensure that the analysts are well represented and effective in their review and impact on the roadmap. He should provide input to the Roadmap Committee.

2) **Budgetary Allocations.** The project lead is responsible for assuring that the DTA budget is allocated according to the priorities established by the roadmap and the oversight committee. The budget must be tracked to assure appropriate expenditures. The budget control should be direct to the funding sponsors rather than complicated by other organizational structures.

3) **Staffing**. The project lead is tasked with recruiting and maintaining the needed staff in the organizational structures, including the oversight committee, the roadmap committee and the section leads.

4) **Organizational Structure**. The project lead must organize the effort, adjust the organization as needed to be effective and see that the organization structure is being utilized appropriately. The organization should insure that the roadmap, the analysts' home page and metrics are being adequately addressed.

1.6.5 DTA Oversight Committee

The oversight committee is the mechanism by which the analysts' community provides direction, review, and approval. This committee is made up of analysts who represent the structures, thermal, and radiation transport communities. They should adequately understand, communicate and represent the analyst community and their priorities and needs. They are also responsible for spearheading and championing the use of the developed DTA products amongst the users. The roadmap committee will provide the technical direction for DTA, but this must be approved and agreed to by the oversight committee. The oversight committee must also carefully review ASC requirements gathered by SEPR/SEG and resolve any anomalies and conflicts.

1.6.6 DTA Roadmap Committee

The roadmap committee is tasked with producing and continually updating the technical roadmap. The roadmap must itemize priorities and deficiencies and should be the basis of any development efforts associated with DTA. It should also estimate where substantial gains should be expected in DTA execution and specify what gains to expect. Risks should be identified and managed as part of the roadmap.

The roadmap committee is responsible for the ongoing roadmap, they should solicit the section leads to provide details to the roadmap for their respective areas of responsibility. They must also ensure that the input they receive is consistent with the overall roadmap and that any integration gaps and non-beneficial overlaps are resolved in the roadmap. They must also obtain approval of the roadmap from the oversight committee, making adjustments as needed to align the roadmap with the oversight committee feedback.

1.6.7 DTA Section Managers

The section managers are responsible for the details of the roadmap with respect to their specific focus areas. They must work with the roadmap committee to ensure that their specific projects are aligned with the roadmap and adjust as needed based on feedback from the oversight committee.

The section managers must also lead their specific development projects, ensuring that the priorities set are subsequently funded by the project lead, that the development efforts in their sections are focused adequately to meet the targets, and that any necessary integration issues are and continue to be addressed.

The section managers are directly responsible to the project lead for any management issues (e.g. funding, personnel, etc.) and directly responsible to the roadmap team for development issues (e.g. direction, priorities, integration, etc.).

The DTA leadership structure described above is illustrated in Figure 1-3. This figure also illustrates the organizations that fund the DTA program.

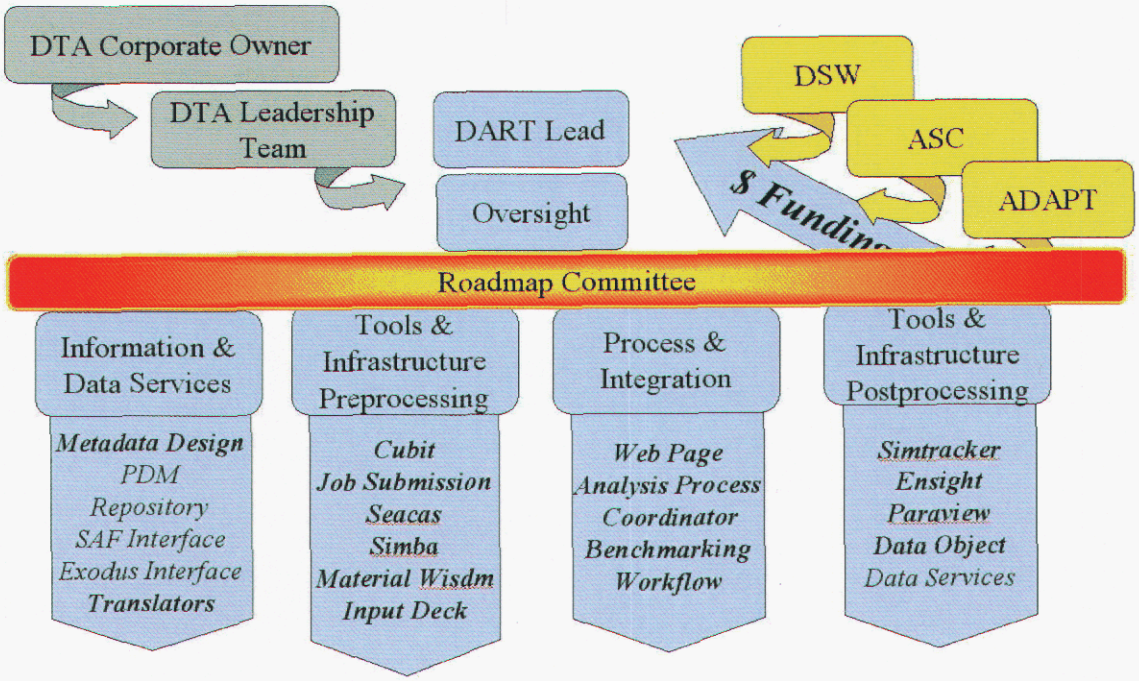

Figure 1-3. DTA Leadership Structure

The DART program as envisioned will provide analysts with access to a verified, validated, accurate, easily understood, and rich set of tools and data to be used to perform modeling and simulation studies in support of design and certification studies.

2 DART Concept of Operations

The DART Roadmap Vision provides the structure for progressive improvements in the DTA environments that will ultimately produce a 90-percent reduction in the DTA cycle time while improving product quality. The plan is based on achieving this through three focus areas: reengineering, metadata management, and integration. Implementation of the plan will be carried out through the DART Program Structure with technical improvements achieved within the four DART Program Sections: Information and Data Services, Pre-Processing, Process Integration, and Post-Processing. Improvement of the DTA process by an order of magnitude will require a very focused and well-managed process. Essential to the success of this process is a very clear definition of the DTA customers and a well-defined listing of the applications and functions that the customers require for the DTA process.

2.1 User Roles and Responsibilities

The following user roles and responsibilities have been identified. They are consistent with the user roles identified in the Engineering Sciences Analysis Process Plan (ESAPP).

2.1.1 Designers

Designers are responsible for creating the Design Solid Model (DSM) that describes the geometry and material specifications of the components and systems. The designers are responsible for following all defined standards relating to geometry creation to ensure maximum usability of the DSM. A subset of this user group is also proficient in creating finite element mesh models for use in modeling and simulation studies.

2.1.2 Analysis Managers

Analysis managers include the managers of the various analysis departments (thermal, mechanical, and radiation transport) as well as the analysis Process Management Team (PMT). This user group assigns analysis projects and tracks the analysis project progress throughout the entire project lifecycle. Monitoring of projects provides early warning signs of cost or performance issues that need to be addressed if project objectives are to be adequately fulfilled. This user group requires access to budget and staffing details of an analysis project as well as scheduling and progress information.

2.1.3 Analysts

Analysts are responsible for leading and performing project work. Projects begin by working with customers and analysis managers to define the problem to be solved and developing options for the technical approach to be used, including associated risks. Analysts then begin developing the Project Work Agreement and Levels of Formality for the analysis project in conjunction with appropriate analysis managers and customers. At the completion of the planning phase, analysts begin the project execution phase that includes identifying potential resources to analysis management, gathering information, developing models, performing the analysis, obtaining specified reviews, creating and

archiving appropriate project documentation, and participating with analysis management in renegotiating project elements as necessary.

2.1.4 Customers

Customers support the analysis project efforts, as appropriate, through participation as it relates to providing necessary input to the analysis project to ensure that problem statements are well defined, risks are understood, costs and schedules meet program/project needs, and final products are appropriate for their intended use. They participate in relevant project discussions, provide information regarding changes to the analysis, negotiate work with analysts and analyst management to create a mutually agreeable Project Work Agreement, defined Levels of Formality, and Technical Effort Plan, and participate in definition and conduct of reviews. The customers need to be kept informed of cost, performance, and schedule that cut across all analysis projects within their program element. The customer requires the ability to monitor project progress, which will improve product quality by ensuring that customer expectations and project deliverables are well aligned.

2.2 Analysts' DTA Toolset

Faster computational capabilities have made it possible to simulate larger and more complex systems. To assist analysts in the development of these large complex models, ASC has funded several problem set-up, post-processing and visualization tools like *Materials WISDM*, *SIMBA*, *CUBIT*, *ParaView*, *Ensight*, *SimTracker*, and *Data Services*. Figure 1-2 illustrates the wide variety of tools and services that are either planned for or are available to analysts to complete one cycle through the existing DTA process. These tools include:

Requirements Resources Planning Tools: These tools are used to clearly negotiate and define the customer's requirements, define the Project Work Agreement and Technical Effort Plan, gather project management metadata (e.g. start date, deadlines, analysis team members, review team, etc.), and support analysis project reviews. The primary tool being used in this area is the Engineering Sciences Analysis Workflow (ESAW), currently in the prototype development phase. It is expected that this tool will be used as an integral part of the Engineering Sciences' formalized analysis process.

Solid Modeling Tools: The Design Solid Model (DSM) is a software-based, geometric representation of a weapon component or system. Different CAD software packages use different underlying technologies and strategies to represent and capture the various parts that compose the system. Sandia, in conjunction with the NWC, primarily uses the commercially available tool *Pro/Engineer*; however, *SolidWorks* use has been increasing in recent years.

Solid Model Meshability Analyzer: A significant amount of time in the DTA process is spent iterating between the analyst and designer making modifications to the DSM to enable it to be meshed. The solid model meshablilty analyzer simplifies this iterative process by giving the designer a tool to determine if the DSM is meshable. Currently, no tool exists to perform this function, however the technology has been investigated and should be developed to help both designers while they are developing the solid models and to help analysts while they are estimating the resources required for the project.

***Meshing Tool*:** The meshing tool is responsible for generation of the discretized mesh. To accomplish this, the analyst first uses it to perform geometric and topological editing of the solid model to transform the model from a Design Solid Model (DSM) to an Analysis Solid Model (ASM). The analyst then works from the ASM solid model geometry description and discretizes the geometry, yielding a mesh model that forms the geometric representation for a simulation study. Sandia has pioneered many advanced meshing technologies that are packaged in a tool called *CUBIT* that includes critical geometry editing, virtual topology overlays and numerous meshing tools. Other meshing tools used within Sandia include *MSC/Patran*, *CosmosWorks*, *SDRC/Ideas*, *TrueGrid*, *AntiPasto*, and *GridGen*.

***Finite Element Model Assembly Tool*:** As mesh models become increasingly complex, analysts do not build single models in isolation but rather they build and manage families of related models. There is an increasing desire to build "plug and play" component meshes at varying levels of fidelity. To accomplish these goals, ASC has invested in the development of a tool called *SIMBA* (Simulation Manager and Builder for Analysts) for building and managing mesh models.

***Mesh Verification Service*:** A mesh verification tool checks the validity of a mesh before it is used in a modeling and simulation study. The service ensures that the mesh model accurately represents the solid model, has proper connectivity, and uses elements of reasonable shape. Sandia has developed a mesh quality and topology checker called *VERDE*. In addition, *SIMBA* contains mesh quality assurance checks that uncover logical inconsistencies in a model (e.g. mass and center of gravity). *CUBIT* additionally incorporates the *VERDE* technology for mesh verification.

***Materials Database*:** A materials database must hold material parameters for the wide variety of constitutive models in Sandia's modeling and simulation codes. The database must maintain these properties for all known materials in the stockpile. To meet these needs, Sandia has developed a model-based materials information system called *Materials WISDM* that allows users to query material parameter sets and format them for use in modeling and simulation codes. *Materials WISDM* also contains a material model driver that, when fully implemented, will allow users to exercise any of the constitutive models in the *SIERRA* framework by applying an arbitrary three dimensional load path to a unit cell and calculating the corresponding response. This capability allows analysts to validate material property sets against test data in the context of the constitutive model.

***Load Balancer*:** Before a simulation can be performed on a parallel computer, it must first be decomposed into tasks that are assigned to different processors. Efficient use of the machine requires that each processor have about the same amount of work to do and that the quantity of inter-processor communication is kept small. Finding an optimal decomposition is very difficult, but due to its practical importance, a great deal of effort has been devoted to developing heuristics for this problem. A variety of algorithms for graph partitioning have been researched, developed, and implemented. Examples of these libraries are *Chaco*, *Zoltan*, and *Metis*. The codes using these libraries are *nem_slice, nem_spread,* and *yada*.

***Job Submission Service*:** With an increasing number of high performance computing resources available to analysts ranging from individual workstations up to the fastest computers in the world, capabilities are needed that allow users to access the resource

and query the job status from all three nuclear weapons laboratories from a single interface. The capability will need to provide desktop and web-based tools that allow users to submit, monitor, and control jobs on both local and remote resources without a single remote login.

***Simulation Codes*:** While beyond the scope of DART, the simulation codes are the scientific computing tools for simulating physics processes. The results of these simulations provide the data from which engineering judgments are made. Sandia has a number of modeling and simulation codes available to analysts, both internally developed and commercially available, for a wide variety of physics disciplines, including thermal sciences, structural mechanics, solid dynamics (*Salinas*), and radiation transport (*ITS Codes*). In addition, Sandia is developing the *SIERRA* and *NEVADA* frameworks to support multi-physics simulations. Sandia analysts also use several commercial simulation codes including *ABAQUS* and *NASTRAN*. Integral to the simulation codes is a library of constitutive models that mathematically represent various response modes of materials. Material specific parameters for the constitutive models are held in the material property database.

***Simulation Process Monitor/Summary Tool*:** Once a simulation run is submitted to a compute server, it is useful for analysts to have the capability of monitoring the simulation progress and collecting summary information such as the number of processors used in the run, simulation runtime, and snapshots of the analysis results. As the simulation runs increase in both size and runtime, visualization becomes increasingly important. Significant attention will have to be given to provide a scalable, 'easy to use' run-time visualization capability.

***Data Mining and Visualization Tools*:** Sandia's ever increasing capabilities to perform simulations of large models of complex systems has greatly increased the difficulty of post-processing simulation results. Data mining and scalable visualization are two areas that currently need significant attention. The processing, movement, and visualization of large datasets can take up valuable time in the end-to-end process. Under the ASC-funded *Data Services* program, data mining tools are being developed at Sandia that help address this problem by simplifying the process of culling, gathering, and manipulating large simulation results. *Ensight* currently serves as the production visualization tool at Sandia. In addition to *Ensight*, the visualization R&D team is deploying several of their scalable visualization algorithms within the open source *ParaView* product. It is hoped that *ParaView* will become the standard deployment vehicle for the visualization research and development efforts.

***Archive Service*:** An archive service allows users to place model artifacts in a repository for long-term storage and retrieval. The Data Services group is working on a tool that will assist the Sandia analysts to perform medium range archiving of simulation data on the High Performance Storage System (HPSS). This tool will be released in early 2004. Long-term corporate-wide archiving facilities still need to be developed.

***Deployment Team*:** A key component to the success of the DTA Program will be the deployment of the toolset to the analysts' desktops and computing environments where they work. A common and coordinated deployment of all the tools should be organized. Currently, each tool is responsible for its own deployment and typically is best employed on the LAN where it is developed. In the future, a team, perhaps consisting of members

of the DTA tool teams, should oversee the joint deployment so that necessary code versions are available to all analysts.

Documentation: The vast number of tools provided in the Analysts' toolset highlights the need for a centralized, organized, and maintained documentation system. A robust, capable, easy-to-use toolset is not very useful if no one knows about it or how to use it. A web site known as "Analysts' Home Page" will be created and maintained. The web page will provide a central location for storing useful information about the current DTA process and tools. All tools in the toolset will be required to be documented and provide access to their documentation via the web site.

2.3 Integration Benefits

In the current analysis process, analysts are individually responsible for finding these tools, having them installed in their work environment, and learning how to use them. An even more difficult task for analysts is trying to make the DTA toolset work together. The DTA tools are functionally independent and do not have well-defined interfaces, mechanisms, or a common language for communicating with each other.

The integrated DTA environment will support a variety of activities that users commonly perform on a daily basis. These activities span the user roles described in Section 2.1 and use the toolset described in Section 2.2. In addition to these common activities, the integrated DTA architecture needs to support additional requirements imposed by the Engineering Sciences Analysis Process Plan [1]. This plan will place many additional process requirements on analysts in the areas of accuracy, reproducibility, and traceability of modeling and simulation artifacts.

The Engineering Sciences organizations provide computational analyses for evaluation of various components, subsystems, and systems. The largest customer of the Engineering Sciences organizations is the Nuclear Weapons community of Sandia National Laboratories (Sandia) and its related Nuclear Weapons Complex (NWC) and Department of Defense (DoD) partners. As a result, most analysis work relates to weapon systems. However, the organizations are also involved in analyses for other customers, including various Department of Energy programs, other government agencies, and industry.

Weapon Qualification studies are an example of analysis activities that will benefit from the DTA effort. A model-based weapon qualification study can generate vast amounts of distributed data, including design solid models, analysis solid models, mesh models, environment specifications, simulation results files, model validation tests, and all supporting documentation. The relationships of the various data artifacts to each other and to the weapon program requirements for which they were performed define the *qualification strategy*. The integrated DTA environment will permit automatic notification when components become out-of-date with artifacts that they use or are derived from. This will make it much easier to ensure that analysis products are based on the most current data and geometry models. By maintaining the relationships of the various data artifacts to each other and to the weapon program requirements for which they were performed, a qualification study can be easily re-executed if a change is made to the system (e.g. a material or component change) or the weapon's deployment environment (i.e. a new weapon carrier system or handling gear). The modified

components or environments could be inserted into the system, and the affected simulations would be automatically flagged for re-computation.

3 Guiding Vision for Improving the DTA Process

The DART Roadmap Committee was formed to establish a roadmap and vision for improving the DTA process. The roadmap committee in DART established three focus areas: Reengineering, Metadata Management, and Integration. The goal of a 90-percent reduction in cycle time while improving product quality will be achieved as the project teams in the DART program focus on these areas.

3.1 Reengineering the DTA Process

Process reengineering includes:

- Eliminating nonessential steps,
- Reducing the time spent in essential steps, and
- Automating noncomplex steps.

The reengineering must occur at both the tool and process levels. Reengineering also includes continued, sustained research and development to improve the functionality of the individual tools. Several problems in the DTA process will most likely not be completely solved in the near future. Problems like automatic hexahedral meshing, construction of billions of finite elements, and post processing of such models are good examples of problems that will need continued research and development efforts, which should not be ignored while shorter-range solutions are implemented for easier problems.

The three areas of reengineering in the DTA process are:

- ***Eliminating nonessential steps***. Process steps that are not needed should be identified and removed. Examples are "CAD translation" and "file spreading during job submission." These are both discussed in more detail later in Sections 3.1.1 and 3.1.2. Additional nonessential steps should be identified, detailed and solved on a continuing basis under the direction of the DART management structure.

- ***Reducing the time spent in essential steps.*** Significant hurdles in existing tools should be identified and targeted for improvement. A few examples of essential steps that are more difficult than they should be are geometry clean-up, advanced hex meshing, generation of large meshes, visualization of large data sets, and interpretation of large data sets or data mining.

- ***Automating noncomplex steps***. Many steps in the analysis process are currently done manually and are tedious and mundane for the analyst. These steps should be automated. Some examples are file archival, file transfer and job submission.

The reengineering of the process occurs throughout the DTA roadmap. The metadata design and implementation, the Analysis Project Coordinator, and the Simulation Data Management (SDM) system can all be seen as examples of reengineering the process. It is important, however, that in the changes made to bring improvements to the DTA process, that continual evaluation and reengineering occurs, and that it specifically does not get removed from the individual tool development.

To illustrate the reengineering vision, a couple of examples are given of how this can occur. Of course the technical details of these changes must be worked out, but the important part of these examples is to illustrate the purpose of re-engineering.

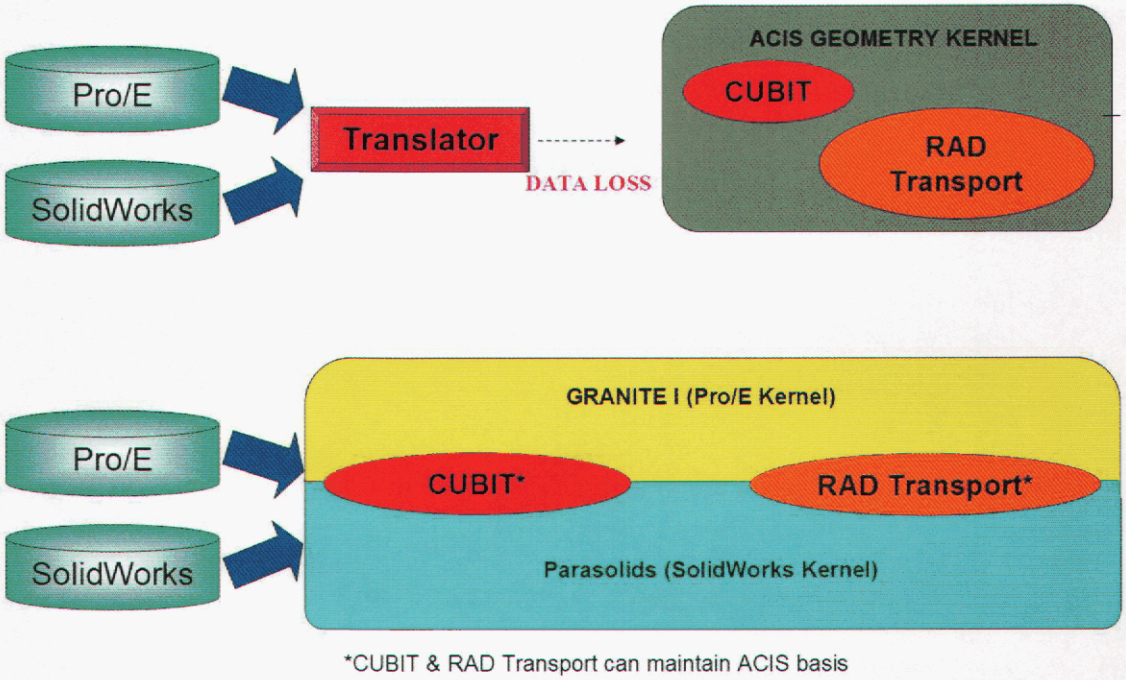

Figure 3-1. Illustration of the CAD translation process: present state (top), and target state (bottom) following process reengineering.

3.1.1 Process Reengineering Example: Removal of CAD Translation

Currently, to perform Radiation Transport calculations, or to use the *CUBIT* meshing toolkit, CAD models must be taken from *Pro/Engineer* where they are created, and translated through internal or third party packages into the ACIS format. This translation process often damages the integrity of the solid model and loses attributes such as material properties, names or notes stored on the model in *Pro/Engineer*. Replacing *CUBIT*'s and *Radiation Transport's* underlying geometry kernel with the *GRANITE 1* kernel from Parametric Technology Corporation (PTC) can eliminate this translation process. The *GRANITE 1* kernel is the same geometric kernel used by PTC in Pro/Engineer and therefore would allow *CUBIT* and *Radiation Transport* to use native *Pro/Engineer* files without translation of the data to a different format and the associated loss of information inherent in any translation process. Another solution for the Radiation transport code is to remove the current direct dependency on solid model geometry and use a facet based geometry that is both more portable to ASC platforms and would

require less computational resources than typical CAD surface representations require.

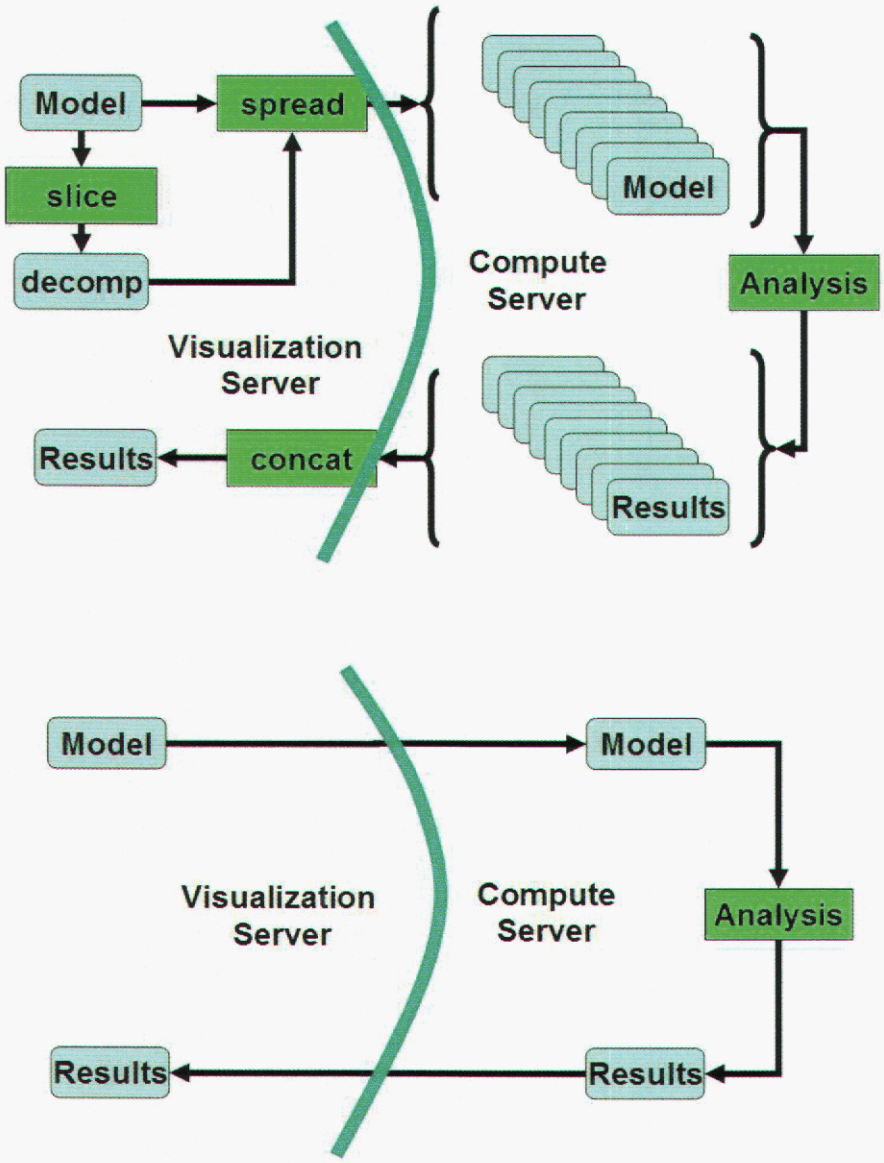

Figure 3-2. Illustration of Job Submission Process. Present State (top), and Process Reengineering Target State (bottom)

3.1.2 Process Reengineering Example: File Spreading Elimination

The second example is removing the file-spreading step in the DTA process. The *ExodusII* results database format used by many of the Sandia simulation codes is not a parallel file format. Each processor in a parallel execution requires a file containing only its portion of the simulation. Therefore, each parallel simulation process contains a 'file spreading' step in which the global mesh file is spread into multiple 'sub files' each containing the processor-specific portion of the mesh for each processor in the simulation. The same requirement applies to the results files generated by the simulation, so there is also a 'file concatenation' step in the simulation process.

The file spreading process could be removed by embedding the load-balancing or parallel decomposition step (see the description of Load Balancer in Section 2.2) into the analysis codes. An initial "dumb" decomposition can be initially performed by the codes to load the model onto the parallel computers followed by a dynamic load-balancing step performed by the *Zoltan* tool to readjust the processor load appropriately. Following the analysis step, the analysis code can either recombine the spread files or submit them to a parallel postprocessing tool.

Elimination of the file-spreading step would remove some of the non-essential complexity in the simulation process. It would also provide some additional flexibility since the analyst would not have to decide how many processors the job would use until right at the point the job was submitted. An additional benefit is that the overall job submission process would be much simpler to automate.

3.2 Metadata Management

A considerable amount of data is generated and consumed by an analyst during an analysis. This includes both

- "Problem-size" data such as the geometry model, the finite element model mesh, and the transient results data; and

- "Metadata" or data about data. There are many types of metadata including level-of-formality of the analysis and the individual mesh pieces; thickness multiplier for shell elements; material specification to mesh element block mappings; processor counts; QA information; units systems; etc.

Currently, the analysts must design their own ways of managing the metadata that they create and ways of accessing the metadata that they require. On a small analysis, this may not be too difficult; but on a large project with multiple analysts and multiple analysis scenarios, the management of metadata can require a considerable amount of time and effort. An even more serious problem is that mismanagement of metadata can result in inaccurate simulation results and wasted effort.

3.2.1 Metadata Management Requirements

In the current analysis process, metadata handling is usually manual. Data must be manually entered multiple times, there is no version control or pedigree of the data, and the various applications all use their own metadata formats.

An improved metadata management process would provide the analyst with improved handling of metadata.

- The process should have a good identification of all metadata providers and consumers and the metadata that they produce and consume.

- Metadata should be entered once, and it should persist for downstream consumer processes.

- The data should be version-controlled and it should be possible to determine where the data was produced and where it is consumed.

- The efficient management of the metadata will require that there is a defined standard for representation of the metadata.

A possible consequence of an improved metadata management system is that similar subsequent simulations could reuse models or portions of previous analysis projects. A crude example of where this currently happens is that an analyst will typically create a simulation input file by modifying an existing input file which happens to be for a similar analysis code or analysis condition. With better metadata management, this reuse will hopefully spread to include the reuse of finite element models and other analysis artifacts, even those created by other analysts.

3.2.2 Example of Metadata Management Needs—Model Generation

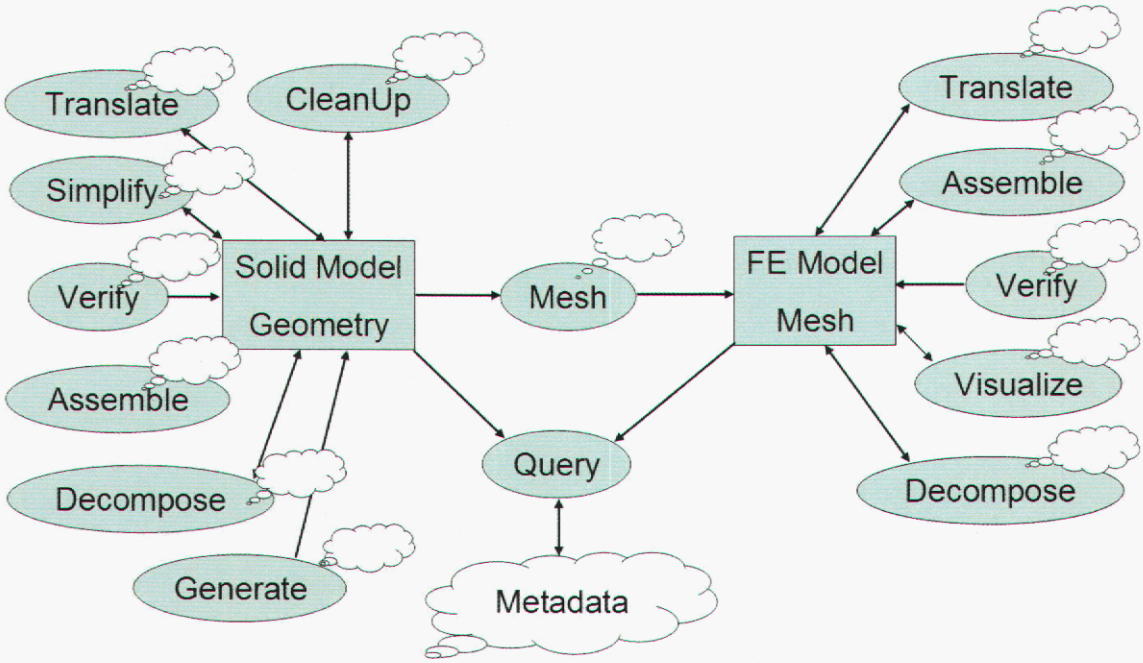

Figure 3-3. Model Generation—An Operational View

Model generation is a useful portion of the overall analysis process. It is used here to help motivate the need for efficient metadata management. In its simplest form, model generation is simply:

- Reading a design solid model (DSM) into a mesh generation program.

- Generating the finite element mesh

- Write the mesh and use it in a simulation.

For any moderately complicated analysis; however, many more processes are required. Examples of these for the solid model include:

- Cleaning up any "dirty geometry" artifacts in the solid model.
- Translating the solid model to the format understood by the mesh generators geometry kernel.
- Simplifying the solid model geometry. Examples include the removal of fillets or screw holes; and the elimination of unneeded components.
- Verifying that the solid model fed to the mesh generation program is a valid representation of the real "design model", especially after the solid model has been through one or more of the processes in this list.
- Assembling multiple solid models into a single assembly.
- Decomposing the solid model into meshable pieces.
- Identifying the material composition of each part.
- Compiling the material properties and constitutive model parameters for each identified part material.
- Generating new solid models that may not be needed for design and manufacturing, but are needed for analysis. Examples include generating a surface that a component will impact or "flow cavities" for CFD analyses.

The analysis model or "mesh" can also require additional processing including:

- Translation from the database format used by the mesh generator to the format used by the analysis program.
- Assembly of multiple meshes into a single analysis mesh.
- Verification that the mesh accurately represents the "design model" and that there are no "malformed" elements, no overlaps, etc.
- Visualization to provide another check that the mesh is an accurate representation of the design model.
- Decomposition of the mesh for a parallel analysis.

Each of these processes generates and/or consumes metadata that must be managed. For example, decomposing a solid model to facilitate meshing creates two or more disjoint surfaces in the finite element mesh that may need to be modeled as tied contact surfaces in the simulation. The analyst currently must manually specify this "tied contact" condition in the simulation input file. A good metadata management system will make it possible for the tied contact condition to be automatically specified in the simulation. If the analyst must manually manage the metadata, he can become quickly overwhelmed.

Although simplifying the analyst's interactions with the various processes and reducing the amount of data which must be entered or reentered manually is a good goal; a good

metadata management system will provide many additional capabilities. These include both obvious needs such as a persistent association of material specifications to geometry and mesh entities and ensuring units consistency between the solid model, mesh, material properties, and loads; and non-obvious needs such as ensuring that the mesh and geometry levels-of-formality are consistent with the project level of formality.

3.3 DTA Integration

DTA integration will provide analysts with

- A common operating environment with single-point access to the entire DTA toolset,
- Improved interoperability between these tools,
- Integrated help on how to use the tools, and
- A degree of workflow management that will guide users to appropriate tools to use in the DTA process.

The goals of DTA tools integration include:

- Preserving worthwhile applications and processes in the current DTA toolset. A significant amount of resources have been invested into the current set of DTA tools. The integrated architecture will leverage as much of these capabilities as possible.
- Define an idealized DTA toolset with well-defined scope and communication paths. The DTA Preprocessing and Postprocessing sections will ensure that there is not inappropriate duplication of capability, and that each of these idealized tools will "do one thing and do it right." The integrating architecture will provide a service layer that will allow services to work together, if need be, to accomplish a specific task. An example of such a common task would be archiving with version control. If this were available, then archiving models or archiving analysis results could both use the common archiving tool. This should be abstracted as a service.
- Provide analysts with single-point access to the DTA toolset through a user interface that will seamlessly integrate tools. The integrating architecture and client user interface will be extensible to allow new tools, as the need arises, to be 'plugged in' to the DTA process. This will allow analysts to customize their integrated environment to suit their needs, discipline (thermal, structural, radiation transport, etc.) and job function (analyst, manager, customer). This single point of access should be developed as the Analysis Project Coordinator. Critical to the successful implementation of the APC are ease of use, extensibility through user customization, and flexibility to include legacy models and processes. To facilitate DTA integration, users will need a common operating environment consisting of the requisite suite of tools

- Allow analysts to maintain current capability and processes. They can later import meshes and input files into the APC. This will allow analysts to slowly migrate to the 'new tools' and for the APC to be deployed without full functionality. Supporting a process that allows incremental adoption will facilitate a smooth transition from current practices.

- Well integrated with metadata management mechanisms. The APC and the DTA tools will be written and maintained such that they comply with the designs and developments in the Metadata project. The APC will be an analyst's point of viewing or accessing the metadata created on his or her project.

- Access to past simulation data from a single entry point that also provides community sharing of data within Need-to-Know authorizations. The Simulation Data Manager (SDM) will provide multiple views of the weapons simulation and access to this data that may be in long-term or short-term archival form.

3.3.1 DTA Tool Integration

The most critical part of the tool integration vision is the management structure employed by the DTA Program team. The management structure must have the authority and funding to influence coordination between the tool teams while providing an environment where technical solutions and changes can be made without consideration of cultural or traditional territories. The result of this, depending on the more detailed technical plan, may include a reorganization or reallocation of the project teams working on the DTA process. Regardless of the technical plan, the management structure must support and facilitate true integration between the projects. Initially, this will include conducting gap and overlap analyses, which will later lead to technical based realignments of the individual projects. Tool integration will rely on the interoperability between the individual tools, with most of this integration and interoperability occurring through the metadata management, which is discussed in Section 3.2.

Tighter integration and overlap reduction can and should be achieved through the sharing of common software modules between the development teams. For example, the meshing and model assembly/input file creation steps can share a common geometry and mesh database to reduce overlaps between the projects. The tighter collaboration between the code development teams will also lead to future collaboration and integration benefits, contrasted by current conditions where competition and duplication have not benefited the DTA process. This does not mean, however, that existing tools should be forced into some new architectural framework. But rather good coding standards for modular code should be practiced to enable sharing and collaboration. Additionally, the tools should not lose their identity and should remain available as stand-alone products to facilitate future tool changes. One current example would be if PATRAN is used rather than CUBIT for mesh generation, a stand-alone tool for model assembly/input file creation should be able to take that mesh and geometry to make the final preparations for running the analysis.

The section leads in charge of the Tools and Infrastructure Preprocessing and Postprocessing in the DTA program should lead the tool project team leaders to define the proper technical solutions for integration including the elimination of the gaps and overlaps.

3.3.2 DTA Process Integration

There currently exists no mechanism for integrating the entire DTA process. The process will be integrated through the creation of two new tools, the Analysis Project Coordinator (APC) and the Simulation Data Manager (SDM). These tools will be additionally augmented by the work done to support metadata management.

The objective of the APC is to provide a single entry point into the DTA process for the analyst. The APC will provide mechanisms for accessing the appropriate tools in the DTA environment to accomplish his or her job. The APC will also provide model management capabilities and an interface into the SDM system, archiving, and the computational grid.

The objective of the SDM system is to provide revision control, revision history, data security, vaulting, relationship tracking, and sharing of the simulation data. The SDM must be accessible through the APC as the analysts' view of the simulation data. Other views should also be provided.

4 DTA Program Vision Details

The DTA program is divided into four main sections: Information and Data Services, Tools and Infrastructure Preprocessing, Process Integration, and Tools and Infrastructure Post Processing. Each of these main sections contains many smaller projects with program plans and roadmaps focused on accomplishing the DTA goals. The majority of these projects are existing projects that have a fairly clear vision of how to accomplish the DART goals and only minor changes to the project plans are needed. However, the *Metadata*, the *Simulation Data Management*, and the *Process Integration* sections contain new initiatives that the DART Roadmap Team sees as vital to meeting DART's goals. Because of this, these three projects are discussed in more detail in this section in order to give a more complete picture of what the Roadmap Team sees as the vital characteristics.

4.1 Information and Data Services

The Information and Data Services section contains two new initiatives--Metadata Management and Simulation Data Management. These initiatives are vital to DART and it is important that the Roadmap Team's vision for them is specified in enough detail that it is clear how they fit in with the existing projects.

4.1.1 Metadata Categorization

A project's metadata is categorized in many ways. A few of these categorizations are illustrated below. Note that these categorizations are neither exhaustive nor exclusive. Each piece of metadata can and will be associated with multiple metadata categorizations and associations.

4.1.1.1 Categorization by Analysis Artifact Association

One categorization is based on the analysis artifact that the data is associated with. Examples of analysis artifact-related metadata categories are geometry-specific, mesh-specific, simulation-specific, and project-specific metadata.

Geometry-specific metadata: Geometry-specific metadata pertains to the geometry or solid model. This may be either a design solid model or an analysis solid model. There may be one or more geometry models per analysis project and each one will have its own specific metadata. Examples of this metadata include:

- The units system of the geometry model.
- The "fidelity" of the model. Is this model the "official design definition" for a weapon system or is it a "preliminary brainstorming" model used to provide some feedback for the design.
- The material specifications.
- QA and version information.
- Format of the solid model (ACIS, Solidworks, Pro/E)

Mesh-specific metadata: Mesh-specific metadata pertains to a mesh model. This is data specific to the meshing process and should not include simulation-specific data. There may be one or more mesh models per analysis project and each mesh model may use zero or more geometry models. Examples of this metadata include:

- The units system of the mesh,
- The thickness multiplier applied to shell elements;
- An indicator that element blocks J, K, L, and Z are derived from body "fireset" in the geometry solid model.
- A reference to the analysis solid model used to create the mesh and a record of the operations performed on that solid model to mesh it.
- An indicator that surfaces X1 and X2 are the result of decomposition needed for meshability and should be treated as a contiguous surface in the analysis model.
- QA and version information.

Simulation-specific metadata: Simulation-specific metadata is data pertaining to the simulation model. A simulation may use one or more mesh models and may generate one or more set of results (binary and/or text). There may be zero or more simulations associated with an analysis project. Examples of simulation-specific metadata include:

- The units system.
- List of material specifications mapped to material properties and constitutive models.
- A reference to the mesh model(s) used in the simulation.
- The analysis code(s) used in the simulation. Note that the capabilities required by the mesh model (e.g. Tied contact) should be checked to ensure that the analysis code supports them.
- The fidelity of the simulation. Is this a fully qualified analysis that can be used as part of a weapon qualification study or is the simulation a scoping calculation performed to help with a preliminary design or to guide the development of mesh models with more fidelity.
- Computer system where the simulation is performed and the number of processors being used.

Project-specific metadata: Project-specific metadata is data describing the overall analysis project. The project may include zero or more simulation models and may also include zero or more "analysis projects." Examples of project-specific metadata include:

- Level of formality of the project.

- The "master" units system
- List of simulation artifacts that need to be archived,
- The weapon system being analyzed, the reasons for this analysis, and
- Stockpile to Target Sequence (STS) Requirements.

It is important that the metadata be associated to the correct analysis artifact to facilitate reuse of geometry, mesh, and simulation models within a project or between multiple projects. The ability to reuse an existing mesh model in a subsequent simulation could be a significant productivity gain.

4.1.1.2 Categorization by Metadata Persistence

Another attribute or property of the metadata is the persistence of the data. An example of long-term or persistent metadata would be a list of the code versions of the tools used during a project. This data would typically not be needed during the execution of the project, but it is important data that is needed for the QA of the project and it must persist for as long as the project is archived.

Transient metadata such as the process id of a running simulation on a certain computer is very important data while the job is running, but has no meaning or use once the job has completed.

4.1.1.3 Categorization by Metadata Levels and Hierarchies

There are also multiple "levels" or "hierarchies" of metadata. Each piece of metadata (at least the persistent metadata) requires a "pedigree" showing where the metadata originated. This pedigree can be interpreted as a form of "metadata of the metadata".

Material property data is a form of metadata, but each material property also has information about its origin (its pedigree). It is important to maintain the pedigree of each piece of metadata so that it can be verified that the data are correct or at least traceable.

4.1.1.4 Categorization by Implicit or Explicit Status

Yet another categorization of the metadata is "implicit" versus "explicit." Implicit metadata is data that can be easily derived from another source and therefore does not necessarily need to be stored. Explicit metadata is data that cannot be derived from another source and therefore must be stored or it will be lost.

An example of implicit metadata would be creating a summary of the data in a mesh model for use by an analysis code input file generator (e.g., *SIMBA*). The file generators need to know the number and type of element blocks, the boundary conditions, the spatial dimension, and other summary data, but they should not need to know how to extract this data from a mesh database. It is more efficient to generate some metadata describing the mesh database and transfer that metadata to the input file generator. This is implicit data since it can be easily derived from the mesh database.

Metadata can change from implicit to explicit and vice versa. An example of metadata changing from implicit to explicit would be material properties. They are implicit since they can be queried from a material database program (e.g. *Materials WISDM*), but once used for a simulation, they must become explicit so that they cannot change since this would result in results data that are in an inconsistent state with respect to the material parameters. A similar case would arise if the user wanted to override one or more material parameter values. Most of the data would be implicit from Materials *WISDM*, but the overridden values would be explicit from the project's metadata. This will probably occur often and must be allowed and accounted for.

4.1.2 Metadata Management Vision

A clear vision and plan of action is needed to get from the current state of metadata management (e.g., none, ad hoc, multiple formats, etc.) to a well-defined, maintainable, traceable, and useful handling of metadata as described in this document. The steps to accomplish this are:

- Identify metadata producers and consumers. This step should be performed in conjunction with the other DTA groups since it entails examining each process in the technology space and identifying whether the process produces metadata or whether it consumes metadata. Note that this also includes identifying metadata producers and consumers outside of the normal analysis project scope, for example, weapons system design processes, STS requirements, etc.

- Once the metadata producers and consumers are identified, the data that are used or created must be identified and categorized. For consumers, the producer(s) of the data should be identified and for producers, the consumer(s) of the data should be identified. This may be one of the most time consuming steps of the metadata process since it involves an in-depth study of each process in the technology space. Since one of the steps in re-engineering the process roadmap also involves an in depth study of each process in the technology space and the linkages between processes, it is a natural synergy to share this step. The two groups should also determine whether the identified data is really needed or whether a re-engineering of the process could eliminate the need for this data.

- Identifying each and every piece of metadata in the entire technology space could take a very long time. To enable the metadata identification process to be performed in parallel with the design and implementation of the metadata management system, it would be beneficial to generate some use cases that include major portions of the analysis process and concentrate the early data identification efforts on the processes in those use cases. It may be beneficial to share the definition of these use cases with the "Integration" roadmap task.

- Once enough metadata consumers, producers, and the data they consume and produce have been identified, the design of the metadata system should begin. This should include:

    - Design the architecture of the metadata "server" which is the process used to take data from the metadata producers and make it available to the metadata consumers.

- Design the metadata format, interface, and syntax. It is highly recommended that this be XML-based and furthermore that it be based on an existing metadata format such as RDF (Resource Description Format) (http://www.w3.org/RDF/) or the Dublin Core Metadata Initiative (http://dublincore.org). Potential interfaces include XMLRPC (http://www.xmlrpc.com) or SOAP (http://www.w3.org/2000/xp/Group/).

- Design a persistence mechanism. Both "short-term persistence" while the analysis project is active and "long-term persistence" when the project is archived are needed.

- Design a "version/change control" mechanism. This is how the pedigree of the metadata is maintained and how a change in a metadata item is propagated (if necessary) to the consumers of that metadata.

- Design a publish/subscribe mechanism so the data producers can publish or create their metadata and the data consumers can subscribe to the data that they require. Traceability should be built into this mechanism.

It is very important that the design of the metadata management system (and all activities in the metadata project) should be done in close communication with the other two activities in this roadmap. The benefits of a well-coordinated and well-designed metadata management process will be a simplified, repeatable, and traceable analysis process that will help the DTA project reach its goal of decreasing the analysis time by 90% and increasing the quality of the analyses.

4.1.3 Simulation Data Management (SDM)

The SDM component shall fill a core group of data management needs, including:

- *Revision Control* – All SDM systems, regardless of manufacturer, provide for revision control of objects. Depending on the system, these objects can range from CAD files to test data to product specifications.

- *Revision History* – SDM systems enable users to see a history of changes to their files. If a user changes a physical feature or metadata element of a model, those changes are tracked.

- *Data Security* – SDM systems also allow companies to control who can see, use, and manipulate their data. CAD files can be locked to prevent unauthorized users from modifying them; drawings can be secured to prevent changes once they have been sent to production.

- *Vaulting* – At the simplest level, SDM systems provide vaulting--a single, central repository for data that reduces the potential for problems caused by multiple local copies or distributed copies that have different configuration information.

- *Relationship Tracking* – No model artifact exists in a vacuum. Components that are used in assemblies can be, and are, changed independently of the entire assembly. Without a SDM system to track the previous vs. latest configurations,

finding and resolving problems can be impossible without causing other problems. This relationship tracking is critical in troubleshooting problems such as described at the beginning of this article.

- *Where-Used Tracking* – In order to track how changes in a simulation or model will affect other downstream products, there must be a method to identify every model that uses that component. A change that may make a component work perfectly in today's new design may make it fail as a component of another dozen current products. Without a mechanism to track these dependencies, the models may become out of date with the originating geometry and material property data.

Beyond these functions, enterprise SDM systems can allow relationships to be built to connect test results to models, vendor quotes to drawings, or machining codes to components.

4.1.4 Simulation Data Archiving

Simulation data archiving (SDA) will provide for the long-term storage and retrieval of analysis information. Features of SDA include:

- Digital warehouse of key analysis artifacts generated in support of weapons work.
- Searchable schema where analysis projects are tied to weapon product structure,
- "Need to know" (access-controlled) viewing of analysis results available to others in weapon engineering community.
- Full support of quality assurance guidelines established by Technical Business Practices.

4.2 Process and Integration

As was discussed earlier, the current DTA tools set was not developed as an integrated suite of applications, but rather as a collection of individual utilities and data resources designed to assist the analyst community in a specific function. This has resulted in a conglomeration of tools which are not integrated, easy-to-use, nor widely distributed.

Concurrent with the formation of DART, the engineering sciences center recently released the first draft of a plan to formalize the analysis process plan (herein referred to as the Analysis Process Plan). In an attempt to provide higher quality products and services to the Defense Programs (DP) customer, the plan addresses three aspects of quality assurance: *reproducibility, traceability, and accuracy*. Reproducibility is addressed in the plan through thorough documentation, archiving of models and all associated artifacts. Traceability is addressed through maintenance of the relationships of the various analysis artifacts, from solid models, mesh models, analysis studies, material properties used in those studies, and all supporting documentation. These relationships need to be maintained for the short-term as the models are being assembled and run. In the long-term, the responsible and efficient management of modeling and simulation artifacts will ensure traceability and promote reuse of models in future engineering studies. Finally, accuracy is addressed in the plan through the definition of a formalized

process for accepting, assigning, executing, reviewing, and approving analysis assignments.

As guided by the principles of DART and the Engineering Sciences Analysis Process Plan, process integration will be achieved through the following activities: the Analysis Project Coordinator (APC), Benchmarking, and the Analyst's Home Page. The following sections describe these activities in greater detail.

4.2.1 Analysis Project Coordinator (APC)

It has been commonly viewed that both the successful implementation of the Analysis Process Plan and the achievement of DART's integration and cycle-time reduction goals will require an integrating application often referred to as the Analysis Project Coordinator (APC). The APC will not achieve integration by being a large monolithic application that will subsume all other DTA applications, forcing them to subscribe to a programming language or style. Rather, the APC will be a peer application that will implement a horizontal integration strategy by knowing how to communicate with the other DTA tools. In this strategy, DTA tools will not communicate directly with one another, but through the metadata layer. The end vision is that the APC will be an integrated development environment (IDE) for analysts where they will spend the majority of their day, from starting a new analysis project through review and archiving.

4.2.1.1 APC General Requirements

The APC vision is a tool that provides the following functionality:

Artifact management. The APC will provide a framework for efficient and responsible management of analysis data artifacts. Support for artifact management encompasses several concepts:

- *Product organizational structure.* The APC will support analysis product management through virtual packaging of the distributed analysis artifacts into logical project packages. Through the APC, analysts will have access to everything from the Project Work Agreement (PWA), Technical Effort Plan (TEP), the analysis data artifacts (meshes, input files, results files, etc.), metadata, and the Final Analysis Report.

- *Management of distributed analysis project artifacts.* The APC will provide users access to tools to efficiently move files to servers for staging, spreading, transfer, combining, archiving, etc.

- *Access to archival tools.* The APC will provide seamless access to archival facilities. The APC will not provide archive facilities, but rather a pluggable interface to introduce archive facilities as they are acquired.

Access to DTA tools. The APC will effectively be an integrated development environment for analysts to perform their day-to-day activities. As such, it will provide access to the wide variety of tools and services used in the DTA process.

- *Single-point access to all resources and tools for all DTA activities.* The APC will integrate DTA tools (e.g. Materials *WISDM*, *CUBIT*, *SIMBA*, *SimTracker* and

Data Services) into a seamless DTA execution environment. The framework will not prescribe the tools that will be used in the analysis process, but will provide an integrating framework that will be extensible to the incorporation of new Sandia-developed and COTS applications as they arise.

- *Artifact based tool guidance.* The APC will provide analysts with resources that will guide them through the DTA process. This will likely be achieved through validation of the metadata layer managed by the APC. For example, the job submission functionality will not be enabled until a model is complete. Model completeness includes the existence of a mesh model, specification of material properties for all mesh blocks, and specification of all job control parameters.

Metadata management. In addition to providing a framework for the storage in analysis artifacts, the APC will assist users in effective management of the links between data artifacts. This will be accomplished through the following functionality:

- *Manage data links.* The APC will manage metadata links *locally* as a problem is in the active stages, and then *globally* when it is checked into the SDM.

- *Where-used tracking of artifacts.* In order to track how changes in a simulation or model artifact will affect other downstream products, there must be a method to identify every model that uses that artifact. A change that may make a component work perfectly in one weapon system may make it fail as a component of another system. Without a mechanism to track these dependencies, simulation-based qualification studies may become out of date with the originating geometry and material property data.

- *Automatic change notification.* The APC will facilitate automatic change notification when derived components become out-of-date with artifacts that they subscribe to, ensuring that analysis products are based on the most current data and geometry models. This can be done through automatic email notification to data artifact owners and by visually flagging these components as out-of-date.

Collaboration. The APC will facilitate collaboration amongst all members of the analysis team throughout all steps defined in the Analysis Process Plan (including the lead analyst, analysts, and reviewers) by providing the following functionality:

- *Change control and change management.* The APC will provide capabilities to check-in and checkout analysis data artifacts from the SDM.

- *Support for multi-user input to a single project.* The APC will enable analysts to create, share and manage analysis project information globally, ensuring consistent approaches and informed collaborative decisions.

- *View management.* View management will provide views into the data framework that are tailored to the role of the individual querying the system. Initially, the APC will provide analyst and project perspectives into the project portfolio. These roles could be expanded in a later version of the APC.

4.2.1.2 APC Implementation Strategy

Many of the requirements defined above for the APC fall into the problem space of many commercially available PDM (Product Data Management) applications. DART intends to utilize PDM technology to support the development of a Simulation Data Manager (SDM). Central to the vision of the APC is that it is highly integrated with the SDM platform and leverages many of the capabilities provided by the underlying PDM, including archiving, version control, change management, and collaborative engineering functionality. That assumption is not overly restrictive as most PDM systems are customizable, allowing custom application development on the PDM framework.

4.2.1.3 Impact of APC on Process Integration

From the DART perspective, a potential speed-up is achieved through the development of an analysis knowledgebase resource. If an analyst needs a model of a component or to see how another analyst approached a similar problem, they have at their disposal a searchable repository of analysis projects where they may find the information they are looking for. This benefits both the analysis and weapons community. If a new analyst is assigned to an unfamiliar problem, they can search the SDM database to learn how a more experienced analyst approached the problem, long after the experienced analyst is gone. If a weapons customer requests analysis services on a component or problem that has already been studied, the project can easily be found and the analysis project resumed right where it left off. The APC, as envisioned, would provide a significant time reduction in either of these cases.

From an Analysis Process perspective, the APC is the analysis project portal where a user can view the entire *project folder* of distributed information. This facilitates the formal review and approval process required by the Analysis Process Plan. It also supports the three aspects of quality assurance of interest: accountability, reproducibility, and traceability. Although DART's primary goal is to reduce the DTA cycle-time, it also has the goal of improving product quality. A formalized process and toolset for supporting a review and approval process prescribed in the Analysis Process Plan achieves DART's second goal of improving product quality.

Finally, from the DP customer perspective, the realization of the APC translates to a more agile model-based engineering infrastructure to support design and qualification of next generation weapon systems.

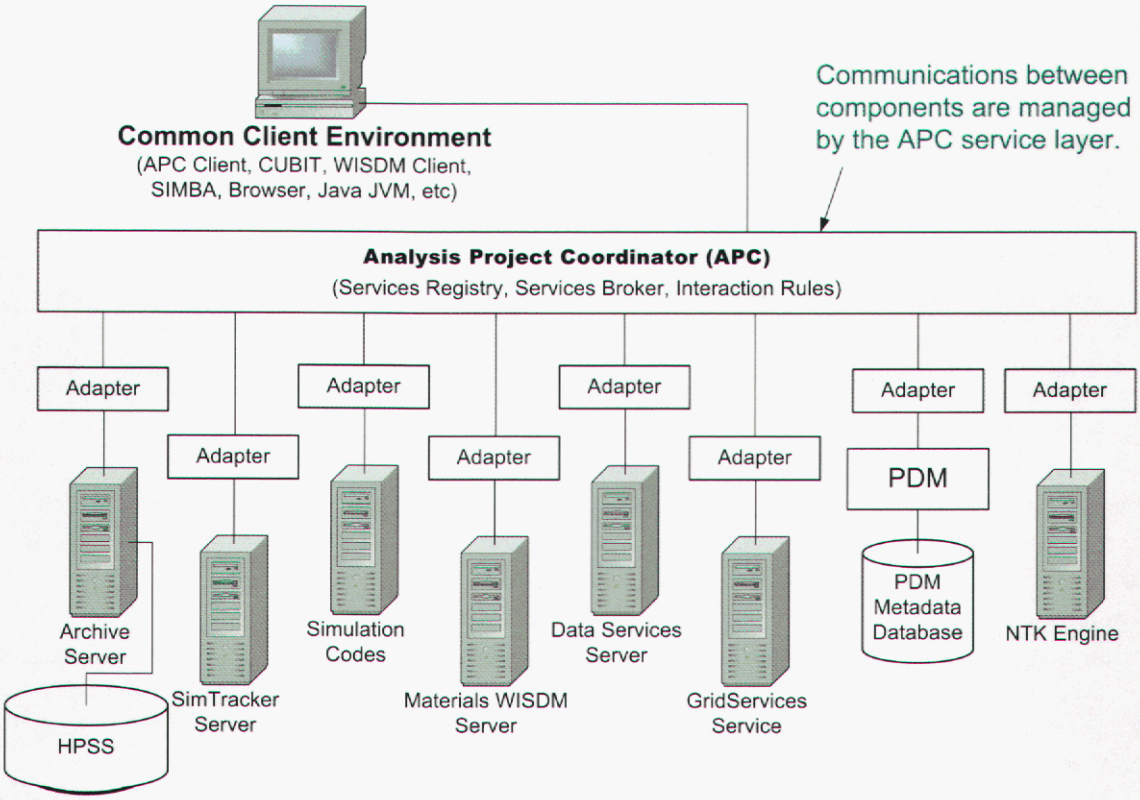

Figure 4-1. Architectural illustration of the APC client interface, common client environment, APC services layer, and the various DTA tools and services

4.2.1.4 APC General Characteristics

- The APC will have hooks in the more global analysis repository or SDM system where coworkers, projects/simulations/geometries/meshes may be viewed and or shared. The APC will also work with the SDM system in a "CVS[1]" manner. This means that at the analysts' choosing, his entire "project" may be committed into the SDM system providing back-up capabilities in addition to sharing. Multiple users may commit to a single more global project where data, mesh, and results may be shared/combined and edited.

- The APC will seamlessly integrate the Workflow requirements into the analysis process allowing documentation and level of formality management.

- The APC will track the project progress and will identify work that remains to be performed, in conjunction with the workflow requirements and a normal process flow (*i.e.,* need mesh, need input file, need to submit job, need to verify results).

- The APC will work in a local environment and not require network connectivity (with the exception of those that require it.). This will allow analysts to use the

[1] Concurrent Versions System. CVS is a version control system, which allows you to keep old versions of files, keep a log of who, when, and what changes occurred, etc. See http://www.cvshome.org/ for more information.

APC on a laptop, at home or in an environment where the global connectivity has not yet been established. In other words, it should not be inherently web-based, but rather web-enabled.

- The APC will also provide interfaces to other engineering resources such as notebooks, calendars, and communication mechanisms.

- The APC will provide a pluggable interface that will facilitate integration of new tools and services as they arise.

- The APC will allow analysts to do their work the way they always have. Analysts will be able to build models using tools of their choice and later check them into the PDM system through the APC. Furthermore, analysts will have access to metadata artifacts, such as analysis code input files, for direct modification. Tools, such as *SIMBA* and *Materials WISDM*, will be available to analysts outside of the APC's integrating framework.

- The APC and/or *SIMBA* will provide an organizational framework for pulling models off the shelf. This model-management framework will allow analysts to build models of appropriate fidelity by selecting and assembling model components from a centralized library.

- The APC will function as the primary front-end to the PDM, providing analysts with the functionality to share models, simulations, or entire projects for later review and approval.

- The APC will permit various levels of project commitment.

    - Check-in: allows the user to place an analysis in the central repository for the purpose of backing it up or sharing it with other users. This analysis can be deleted at a later date at the data owner's discretion.

    - Publish: allows the user to add the analysis to the project. This can only be deleted with the appropriate approvals from upper management.

- The APC will permit late-time importing of analysis projects that were developed outside of the context of the APC.

- The APC will provide mechanisms to annotate the products, as well as capturing any design/analysis intent or knowledge gained. This capability is typically referred to as an *engineer's notebook.*

- The APC will manage the creation and maintenance of linkages between simulation artifacts. For example, the APC will maintain the linkages of mesh models to the Analysis Solid Model, and the Analysis Solid Model to the Design Solid Model

- The APC will be the starting point for parameterized searches for analysis project packages and all associated data artifacts and metadata. Essentially, the APC will be the primary interface to the SDM layer.

4.2.1.5 APC Engineering Sciences Portfolio Management Interface

The APC needs to provide alternative hierarchies for tracing weapon system simulations. Some examples include:

- *Bill of Materials (BOM) Perspective*: Through this perspective users will be able to search through a weapon system bill of materials tree hierarchy to find simulation studies performed for each system, subsystem, and component. For example, a user may direct his search at the W76 system, AF&F subsystem, and down to a particular MC numbered component to find a collection of modeling and simulation studies performed in the design and certification of that component. These studies would include all disciplines (structural, thermal, radiation transport, etc.) unless the user narrowed their search further to a particular discipline. An example of this search path is illustrated in Figure 4-2. This perspective requires direct linkage to EBOM and/or the NWie portal.

- *Weapons Program Work Breakdown Structure (WBS) Perspective*: Through this perspective users will be able to search the analysis archives based on the hierarchy of the weapons system work breakdown structure.

- *Model Manager Perspective*: In addition to allowing users to store and retrieve mesh models, the Model Manager Perspective will allow users to search for simulation studies that were performed using a given model. This linkage will permit forward notification of all dependent modeling and simulation studies should a mesh model be updated. This perspective is similar to the BOM perspective except that is mesh model based. This perspective would require a linkage to *SIMBA* to facilitate model retrieval and construction.

Other perspectives are possible. Figure 4-2 illustrates how these perspectives would allow a user to find the same analysis project through different search paths.

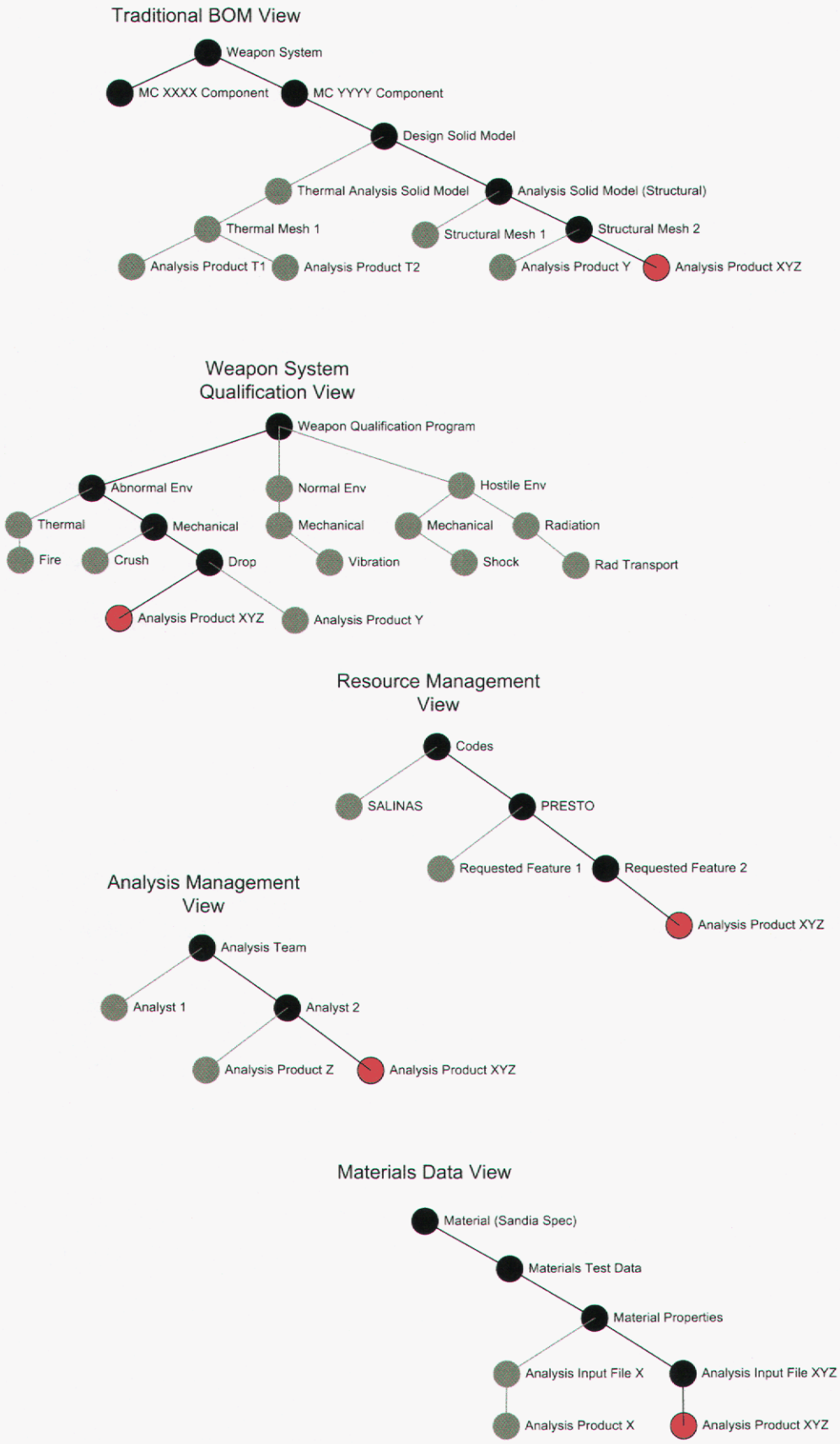

Figure 4-2. APC Portfolio Manager will provide alternative perspectives to organize analysis projects.

4.2.1.6 APC Implementation

- The APC will not be an over-arching application, but rather a horizontally-aligned peer application that manages workflow and metadata. Nor shall it define standards for how all 'sub-applications' will be written. Instead, the APC is a peer application that manages metadata and loosely couples DTA tools.

- The APC shall be incrementally developed with analysis oversight.

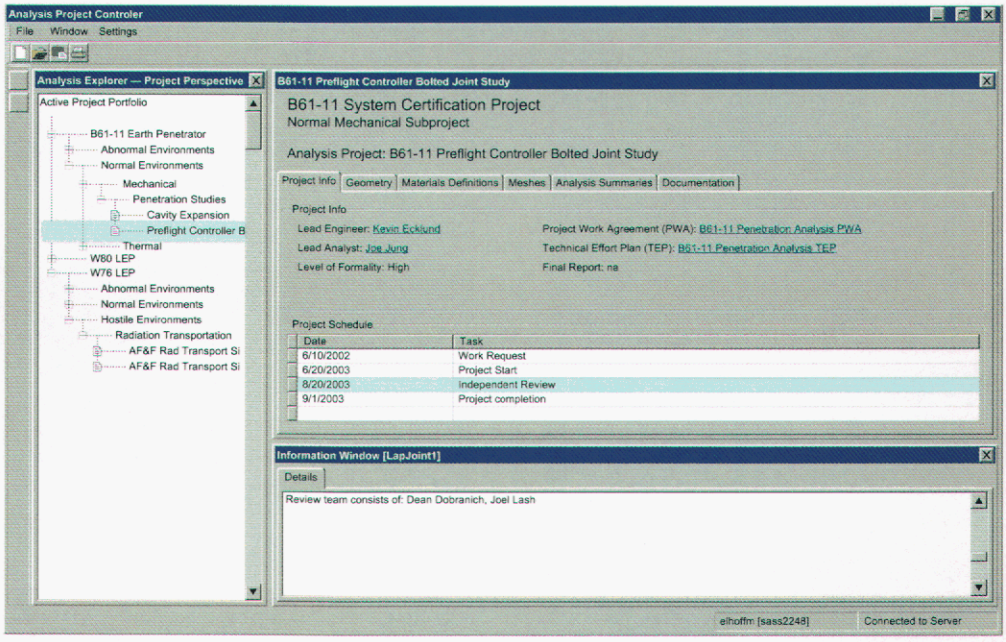

Figure 4-3. Illustration of APC presenting project management information.

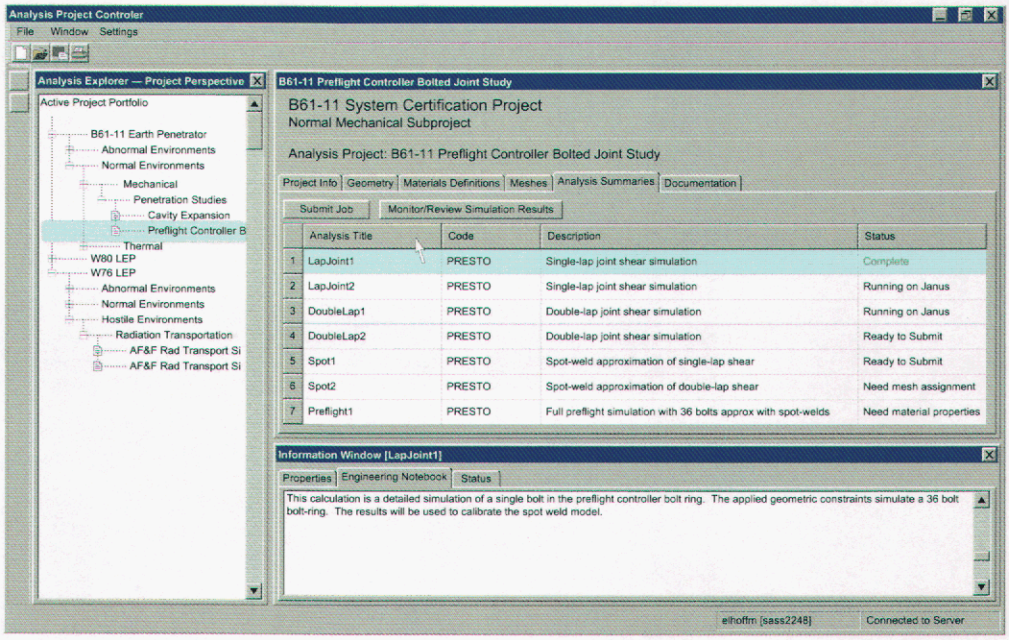

Figure 4-4. Illustration of APC presenting analysis project summaries.

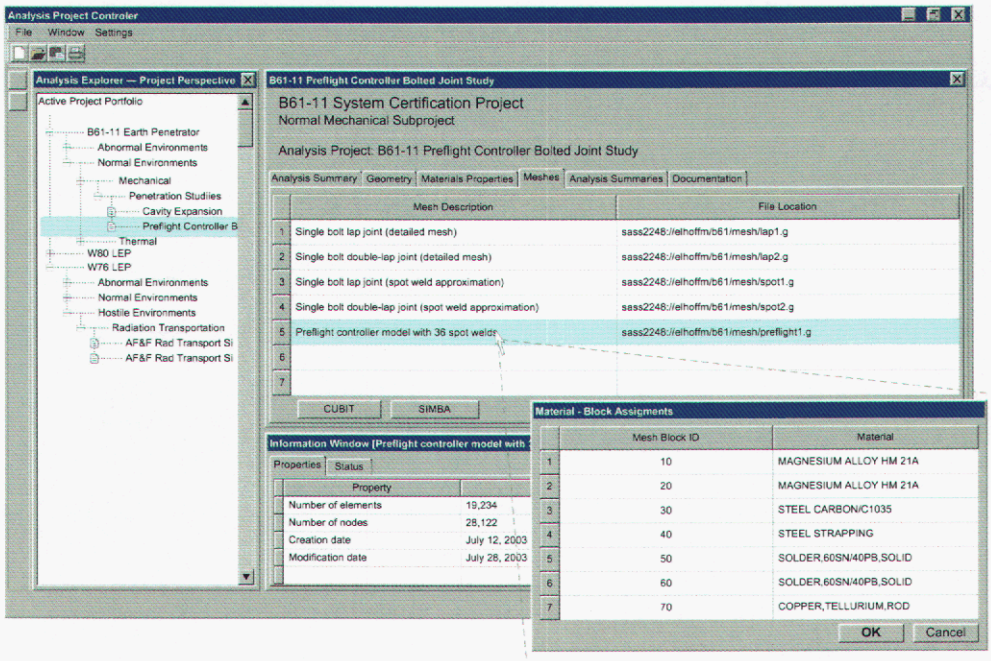

Figure 4-5. Illustration of APC being used for managing analysis models.

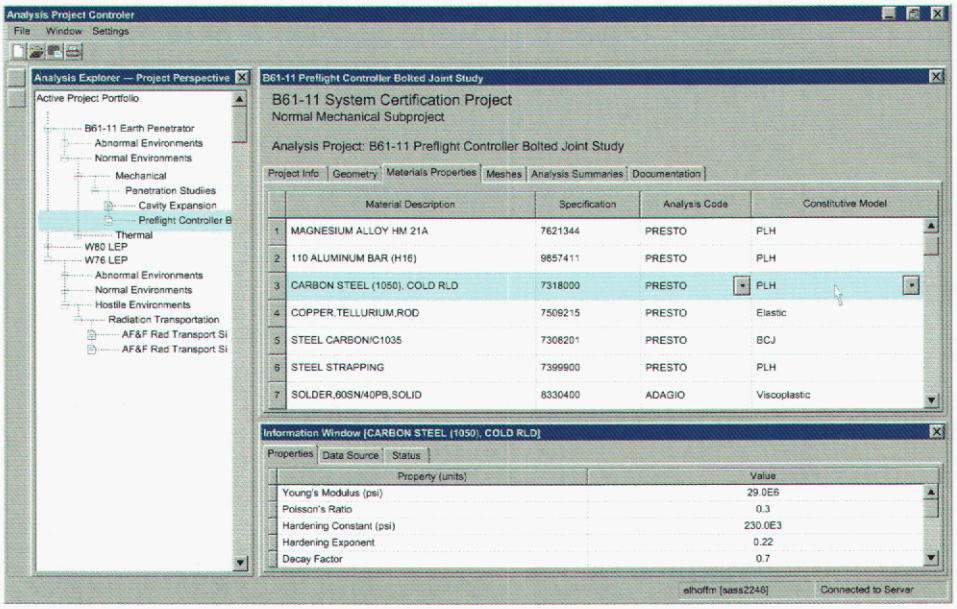

Figure 4-6. Illustration of APC managing material specifications and mappings to property information for an analysis project

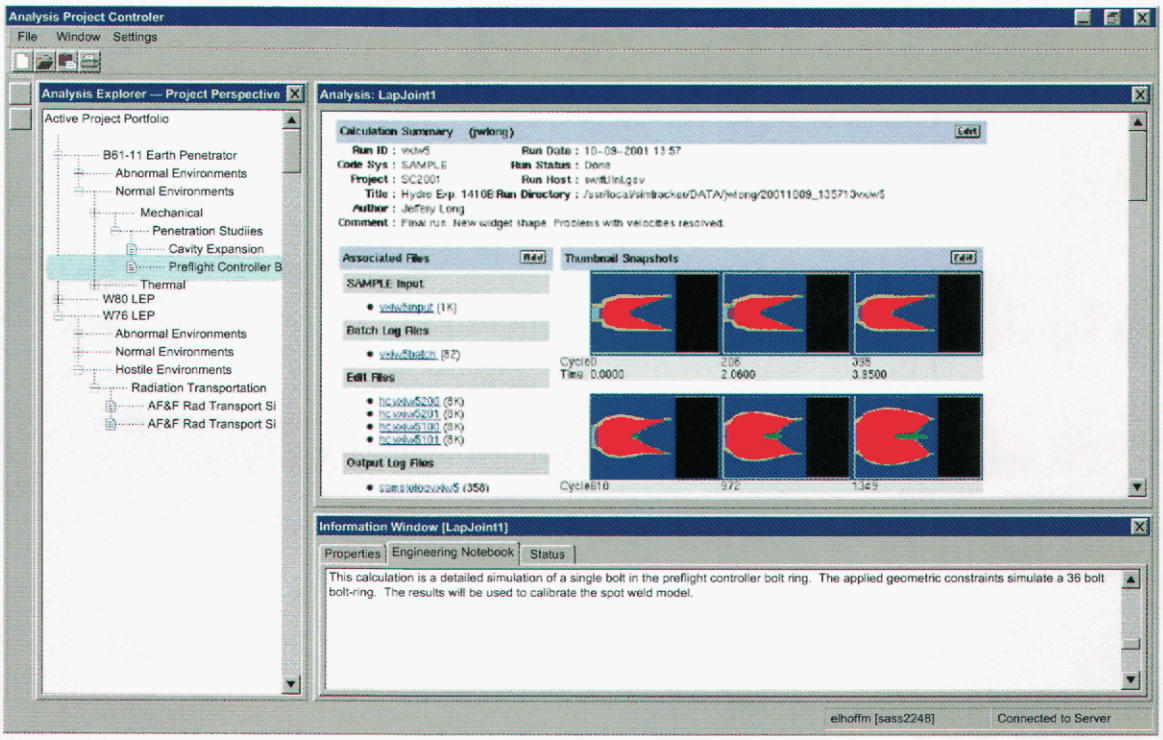

Figure 4-7. Illustration of APC managing and displaying simulation results data managed by SimTracker

4.2.2 Analysts' Home Page

A robust, capable, easy-to-use toolset is not very useful if no one knows about it or how to use it. A vital component of DART is the creation and support of a web site known as the "Analysts' Home Page." This web page will present the information for the DTA process in an easily accessible and useful format. The web page will also provide a central location for storing useful information about the current DTA process and tools. This important project will have a dramatic affect on reducing DTA process time.

4.2.3 Metrics

Since the major goal of DART is to reduce the DTA cycle time by 90-percent, it is very important to have an associated metrics effort to provide quantitative measurements of the process improvements. The metrics can also identify areas where resources can be used efficiently and as a means of identifying which DTA analysts are using tools and which tools they are using. The metrics effort will be ongoing over the life of the DART project.

5 Conclusions

The Design through Analysis Realization Team (DART) will provide analysts with a complete toolset that reduces the time to create, generate, and examine a computational simulation. The toolset will be both easy to learn and easy to use. The DART Roadmap Vision provides for progressive improvements that will reduce the Design through Analysis (DTA) cycle time by 90% over a three-year period while improving both the quality and accountability of the analyses.

The DART program as envisioned will provide the weapon systems analysts with access to a verified, validated, accurate, easily understood, and rich set of tools and data to be used to perform modeling and simulation studies in support of weapon system design and certification studies.

The basic vision of DART has been described in this document; it is now time to develop project plans and project structure to turn this vision into functioning products. It is expected that there will be major and minor changes to the vision described herein and that this document will become rapidly out of date as vision is transformed into reality.

References

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2. Sanchez, P. "Sandia National Laboratories Engineering Sciences Analysis Procedures," 2003.

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