COST-EFFECTIVE PRODUCT RELIZATION: SERVICE-ORIENTED ARCHITECTURE FOR INTEGRATED PRODUCT LIFE-CYCLE MANAGEMENT

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Abstract: The worldwide availability of technology, capital, information, and labor makes today's manufacturing enterprises global. Information incompleteness, inconsistency, and improccessability are problems that collaborative design groups are facing. There is a need to improve the current product development process by allowing distributed and real-time collaboration, endorsing knowledge sharing, and assisting better decision making in product life-cycle management. This will fundamentally transform product development to achieve significant reduction in time to market and cost. This paper addresses a new integration environment that enables the evolution of collaborative *e*-design paradigm. This design paradigm aims at seamless and dynamic integration of distributed design objects and engineering tools over the Internet. A service-oriented architecture is introduced to ensure design collaboration, good interoperability, scalability, extensibility, and portability of the engineering tools. The *e*-design environment transparently integrates overall product life-cycle management activities, including conceptualization, detailed design, virtual simulation and testing, and supply chain management. *Copyright © 2004 IFAC*

Keywords:

1. INTRODUCTION

Today, manufacturing enterprises are globalized with the world-wide availability of technology, capital, information, and labor. Faster change in market demand drives faster obsolescence of established products. Global marketing competition makes manufacturers more conscious of quality, cost, and time-to-market. This distributed economic and technological environment poses a challenge of how to manage collaborative engineering, that is, how to let engineers collaborate globally during the product development period. In recent years, the Internet has evolved rapidly and has made enormous impact on the whole spectrum of industries. The application of network technologies in manufacturing is indispensable because manufacturers face numerous challenges in the practice of collaborative design: lack of information from suppliers and working partners; incompleteness and inconsistency of product information/knowledge within the collaborating group; incapability of processing information/data from other parties due to the problem of interoperability. Hence, collaborative design tools are needed to improve collaboration among distributed design groups, enhance knowledge sharing, and assist in better decision making. There now exists many computational tools in those different areas. However, there are many problems that inhibit them from working together transparently and seamlessly without human intervention. Problems mostly come from the lack of common communication protocols, such as different CAD data formats, different computer operating systems, and different programming languages.

This paper addresses a new integration environment that enables the evolution of collaborative e-design paradigm. This design paradigm aims at seamless and dynamic integration of distributed design objects and engineering tools over the Internet. e-Design involves conceptualizing, designing and realizing a product using tools that allow for interoperability of remote and heterogeneous systems, collaboration among remote supply chain and multidisciplinary enterprise product design team stakeholders, and virtual testing and validation of a product in a secure Internet based information infrastructure.

An e-design system is an integrated product development environment that allows for customers, suppliers, engineers, sales personnel, and other stakeholders to participate in product lifecycle management, while shortening product development time and cost. This integration should be realized by using a service-oriented infrastructure. Service provides functional use for a person, an application program, or another service in the system, which is the core for integration of engineering tools. Various computational engineering tools make certain services available to other design participants in a network-based distributed environment. Instead of traditional client/server relations, peer-to-peer relations exist among service providers. The services that are provided by different engineering tools are published by a service manager, and are available within this distributed environment.

2. BACKGROUND

The advent of the Internet and World Wide Web (WWW) introduced a new wave of research on collaborative product development environment. There are two major research areas in this field. One is the research on how to manage product life-cycle information effectively within a distributed enterprise environment. The other is on network-centric concurrent design and manufacturing, which concentrates on new product design and manufacturing methodology facilitated by network technologies.

In the first research area, research topics comprise of the integration of product and process information temporally and spatially. The product information for the whole life cycle needs to be stored and retrieved enterprise-wide. The accessibility, security, and integrity of information are of the major concerns. By merging the processes of design documentation and design data management through linking CAD drawings with external network-accessible relational databases, integrated geometric information and related documentation can be shared enterprise-wide (Maxfield et al., 1995; Dong and Agogino, 1998; Roy and Kodkani, 1999; Huang and Mak, 1999; Kan et al., 2001). This group of research utilizes existing network protocols to achieve enterprise-wide communication. Some research focuses on agent-based communication methodology over networks. Those researchers (Kumar et al., 1994; Sriram and Logcher, 1993; Huang and Mak, 2000) considered the following research issues of collaborative design system: multimedia engineering documentation, messages and annotations organization, negotiation/constraint management, design, visualization, interfaces, and web communication and navigation among agents.

In the second research area, research is more focused on the feasibility for product design and manufacturing collaboration by the aids of networked computers in a distributed environment. The importance of design collaboration has gained attention of industry (NSF Workshop, 2000; FIPER, 2003; OneSpace; Windchill). Meanwhile, the possibility of distributed environment for product designers and manufacturers has been studied by several academic research groups (Chui and Wright, 1999; Wagner et al., 1997; Kao and Lin, 1998; Larson and Cheng, 2000; Qiang et al., 2001). Some research utilizes middleware technologies for communication in the areas of feature modeling, feature recognition, and design composition (Han and Requicha, 1998; Abrahamson et al., 2000; Lee et al., 1999).

Instead of looking at various engineering tools from traditional computation viewpoint, as above researchers have done, e-design focuses on the engineering implication of those tools from a more abstract level. This approach assures good openness of collaborative engineering systems. The Internet is no longer a simple network of computers. From an application perspective, the Internet is a network of potential services. Functional views of services need to be clearly defined during the design of an Internet-based distributed engineering system. The information supply chain (from customers to product vendors and makers) is required to deal with several information issues including life cycle needs; protection and security; seamless sharing of information across international boundaries; storage/retrieval and data mining strategies; creation of a knowledge depository; classification in the depository (proprietary, public and shared) along with the means to deposit information and knowledge into corporate memory; maintaining and representing the interpretation of information for use by down stream applications and processes; information interpretation for consistency; and record of reasoning process.

In this paper, the concept of service-oriented product engineering architecture is presented to make e-design system cost- and time-effective. By using service-oriented e-design system, customers, designers, manufacturers, suppliers, and other stakeholders can participate in early stage of product design so as to reduce the new product development cycle time and cost.

3. SERVICE-ORIENTED ARCHITECTURE

Integrated product engineering requires collaboration of various engineering tools from various disciplines, such as aesthetic, drafting, material, manufacturing, quality, marketing, maintenance, and government regulations. The Internet provides an opportunity for these engineering tools to work together and utilize these services optimally. To connect these “islands of automation” transparently, universally accepted protocols should be defined at different levels.

In service-oriented architecture, any service can be integrated and shared with architecture components in a legitimate network. To utilize this architecture, services should be specified from the functional aspect of service providers. To make an existing tool available online or to build a new tool for such a system, services associated with this tool should be defined explicitly. The service transaction among service providers, service consumers, and the service manager within e-design system is illustrated in Figure 1. Once a service is registered at a central administrative manager, it is then available within the legitimate domain. This process is service publication. When a service consumer within the system needs a service, it will request a lookup service from the service manager. This process is service lookup. If the service is available, the service consumer can request the service from the service provider by the aid of the service manager. Most importantly, this service triangular relationship should be built at run-time. The service consumer (client) does not know the name, the location, or even the way to invoke the service from the service provider (server). The collaboration between engineering tools is established and executed based on the characteristics of services that can be provided.

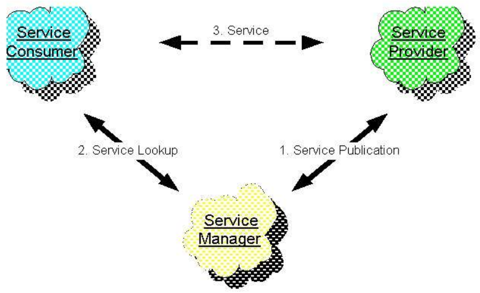


Figure 1: Service triangular relationship

Service publication and lookup are the primary services provided by the Service Manager. As depicted in Figure 2, service publication for service providers includes name publication, catalog publication, and implementation publication. Name publication service is similar to the white-page service provided by telephone companies, by which the name of the service provider is published. Catalog publication service is similar to the yellow-page service: the name and the functional description of the service are published. Implementation publication service is the procedure by which the service provider makes its implementation and invocation of services public so that clients can invoke the service at run-time. Service lookup for service consumers includes name lookup, catalog lookup, and interface lookup. Name lookup service is provided so that consumers can locate the service providers based on the service names. Catalog lookup service is for those consumers who need certain services according to their needs and specifications but do not know the names of the services. Interface lookup service is to provide a way such that consumers can check the protocols of how to invoke the service.

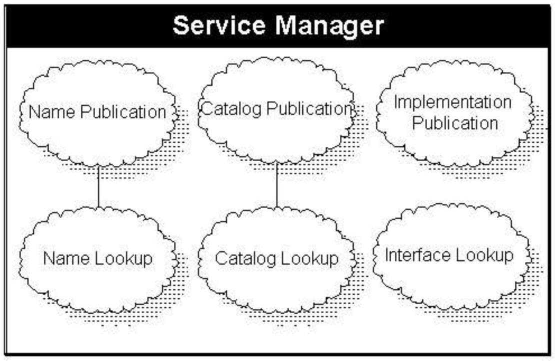


Figure 2: Services provided by Service Manager

A cost-effective collaborative design system should consider: security (which includes access control, identification, authentication, and auditing); concurrency and consistency; heterogeneity and transparency (which includes transparency of access, location, performance, and scaling); inter-process communication; naming (which separates physical and logical names to preserve scalability and transparency); scalability; and resource sharing and management. It is also desirable to reduce the coupling and dependency of data, control information, and administrative information.

4. SERVICE-ORIENTED E-DESIGN INFRASTRUCTURE

In order to shorten product development life-cycle, thus reduce overall cost, an open system for ease of collaboration is needed. The openness provides required extensibility, portability, interoperability, and scalability. In this paper, a service-oriented architecture is employed to conceptualize a future collaborative development environment (i.e., e-design). In a service-oriented e-design architecture, service providers that provide different services such as drafting, assembly, manufacturing, analysis, optimization, procurement, and ergonomics can be developed independently. As showed in Figure 3, servers that provide different engineering services (which are represented by nodes) are linked by the Internet. Each node in this network may require or provide certain engineering services. Thus, it could be a client or a server for different services depending on whether it is the recipient or the provider of such a service. The client/server relationship is determined at run-time. The system is open for the future expansion and extension, in case that more services are available. Plug-and-Play (PnP) is an important consideration of this structure.

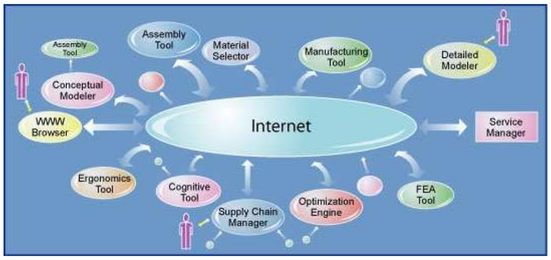


Figure 3: e-Design System Architecture

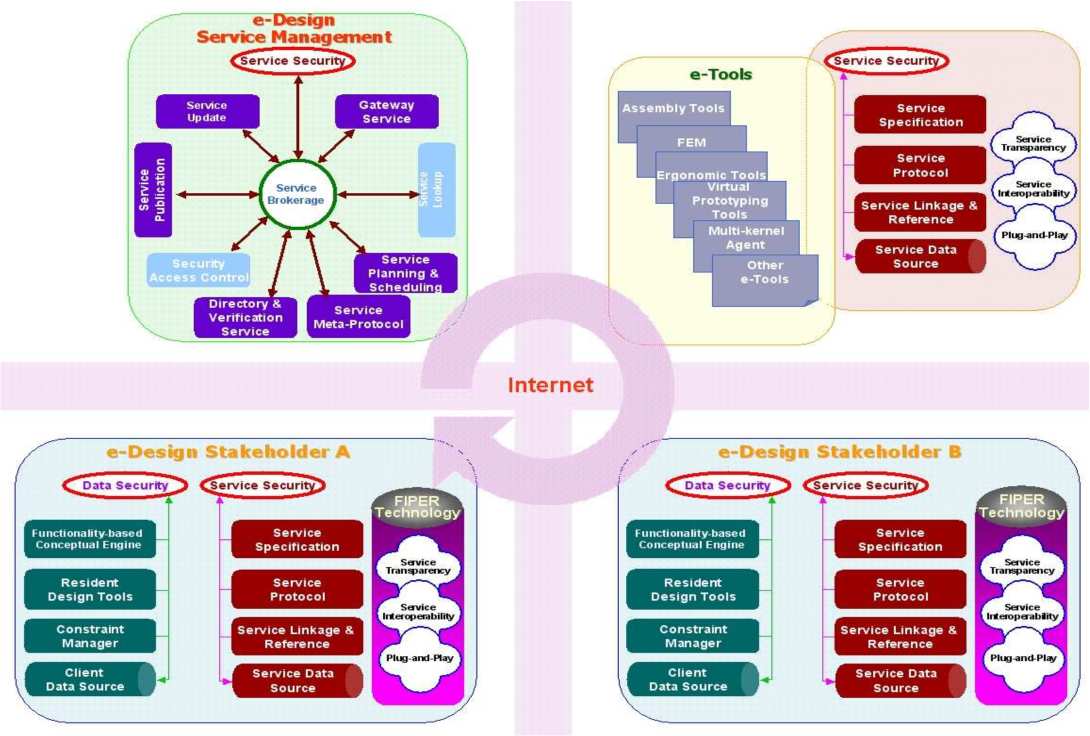


Figure 4: Service-oriented e-Design Information Infrastructure

Figure 4 illustrates the service-oriented e-design information infrastructure. The demonstration illustrated in this figure is named Pegasus Designer System. This infrastructure includes three major components, (i.e., e-design service management, e-tools, and participating e-design stakeholders). These components are integrated through the Internet and share their resources. The e-design service management components provide administrative services (that is brokerage service). Each e-tool has its own services defined. For example, the FEA tool provides the services of product finite element analysis to analyze engineering properties. As another illustration, the ergonomics tool provides product ergonomics analysis. During service transaction, an e-tool may request multiple transactions in collaboration with other e-tools. The e-design stakeholder, (i.e., an enterprise) can have its own collaboration network. The intra-enterprise collaboration can be managed by the e-design architecture. In addition, the architecture can realize enterprise-to-enterprise (i.e., inter-enterprise) collaboration. This service transaction chain should be transparent to the stakeholders. The following sub-sections explain the components of the e-design infrastructure in more detail.

4.1 e-Design service management

The service management builds a bridge between stakeholders and e-tools, in which engineering services are defined, queried, dispatched, and protected according to real-time requirements. The management tasks can be performed in a central service provider as well as distributed service managers. The required services provided by this management role include:

- *Service brokerage*: It allows a transparent and extensible service transaction between stakeholders and e-tools, where distributed and specialized computational tools can be developed and interconnected in a modular way and dedicated e-tools can serve more effectively.
- *Service publication*: It allows for e-tools or third-party agents to publish engineering services for legitimate clients so that open information flow can assist community communication.

- *Service lookup*: It is a directory service provided for stakeholders or third-party agents to query and retrieve engineering service meta information.
- *Service subscription*: It provides different levels of client access to service and allows ease of service customization.
- *Security and trust management*: It ensures secured system for service brokerage and secured information transaction so that collaborators can have a trustable and accountable environment.
- *Service certification*: It ensures security and quality of services by an independent certifier for e-tools as well as brokers.
- *Service planning and scheduling*: It handles distributed resource management (such as differentiation of services and distribution of jobs among service providers with identical services, and throughput and service cycle-time).
- *Service update*: Service version control which maintains consistency for interface and implementation.
- *Protocol publication* (service meta-protocol): Service provided for service brokers. It provides meta-information about service protocols such that brokers can lookup and update as necessary.
- *Financial accounting management*: It allows financial compensation transactions for e-tools being monitored and managed in the pay-per-use service model.

4.2 e-Tool

e-Tools can be any hardware and software resources providing engineering services. Example can be engineering solvers (e.g., finite element analysis (FEA) and computational fluid dynamics (CFD) solvers), information database/knowledge base (e.g., material library, part library), web servers (e.g., ontology server), intelligent agents (e.g., design and assembly advisors), as well as computing servers (e.g., high-performance computing group, supercomputers). To be seamlessly utilized as e-Tools, the tools should be implemented considering following issues.

- *Service specification*: Detail definition of service, such as name, type, function, metrics, and version, etc.
- *Service protocol*: Interfacing protocol, input and output parameters, detailed implementation, and brokerage requirement (such as implementation requirement).
- *Service linkage and reference*: Other service providers/third parties, which are required for the service, should be specified and referred.
- *Service data source*: necessary data and information for all above functions.

4.3 Enterprise Collaboration

In this paper, design collaboration is categorized based on different aspects including the types of requests, the scope of collaboration, and the characteristics of transaction. Collaboration types should be first considered when building collaboration relations.

When the types of service requests are considered, two design collaboration cases can be found. A client may request services directly or service providers themselves based on the requirements of performance, complexity of the service, as well as the frequency of the service.

Service request: For a complex or rare service, the client submits a service request and receives a result from available service providers.

Service provider request: For a simple or recurrent service, tools (such as a plug-in for Excel) are downloaded for a local use.

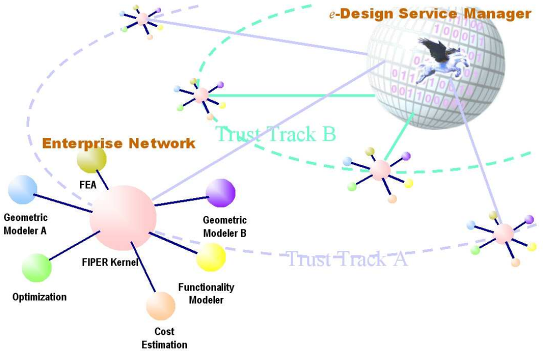


Figure 5: Intra- and Inter-enterprise collaboration

In context of the scope of collaboration, the design collaboration can be classified into two cases. A client may request services within the enterprise or across the boundary of the enterprise based on the availability of service.

- *Intra-enterprise collaboration*: Collaboration within an enterprise where firm's collaboration policy is easier to embody. As shown in Figure 5, a collaboration network can exist within an enterprise.
- *Inter-enterprise collaboration*: Collaboration among enterprises where collaboration policy should be strictly followed and trust and contract management is required. Thus, more overhead is involved. Figure 5 illustrates the concept of collaboration among multiple enterprises (inter-enterprise collaboration). This collaboration can be realized based on a legitimate trust track.

A client may request services with different patterns of service cycles, either single cycle or multiple cycles. This affects the specifications, protocols, and performance requirements of services when collaboration is defined.

- *Single cycle transaction*: By one cycle, service final results can be obtained.

- *Multiple cycle transaction*: It requires multiple cycles and may use service manager multiple times.

The service-oriented e-design environment should be able to allow those design collaboration cases.

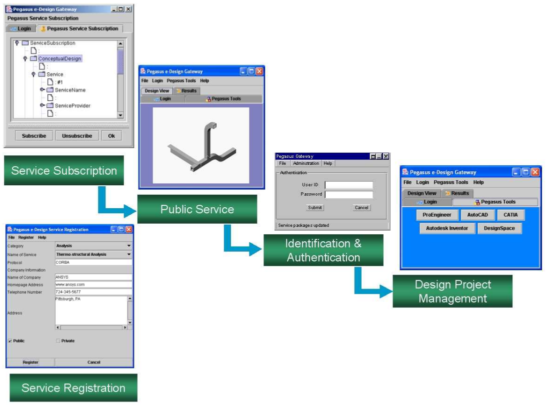


Figure 6: e-Design Service Set-up

4.4 e-Design Infrastructure Requirements

To fully realize the service-oriented e-design environment, the e-design infrastructure should meet the requirements from various design and analysis aspects in collaborative design, as listed in Table 1 (Annex 1).

5. COLLABORATION SCENARIOS

To satisfy the openness requirements, such as extensibility, portability, interoperability, and scalability, a service-oriented architecture is a core concept of e-design systems. In the service-oriented architecture, various engineering services should be available to e-design stakeholder. Figure 6 illustrates a procedure to make the services available for clients. When a company wants to make its service available for e-design stakeholders, the company needs to register its service by providing various information (e.g., company information, service name and category, and transaction protocol). An e-design participant or stakeholder needs to subscribe service. Through this service subscription process, services are classified into visible or invisible services. A set of services can be formed as a "bundle," such as conceptual design tools. All e-design participants can access public service, which provides fundamental services, such as graphic viewer. However, to use the subscribed services, the participants must go through an identification and authentication process. The subscribed service will be displayed through a common interface, called *e-design gateway*.

The e-design gateway provides an environment customized for a participant's design project. Each enterprise or participant may require different design environment due to the different characteristics of their project. For example, if a design project is generative in nature and is to conceptualize design specifications without having a previous design, the project will require conceptual design tools, such as a functionality-based design tool. But, if the project is based on an existing design, this project will require CAD tools compatible to the existing design. Especially, in case where the designs are from different CAD systems, the relevant interoperable environment must be set up. Figure 7 illustrates different design projects of multiple enterprises and examples of customized e-design gateway.

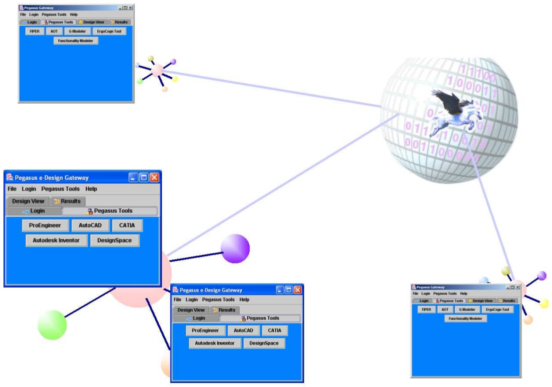


Figure 7: e-Design gateway and customization

Figure 8 shows a procedure of e-design project customization. By specifying project type (e.g., new or existing project), collaboration type (e.g., enterprise-wide or enterprise-to-enterprise collaboration), existence of an initial model, and system environment (e.g., CAD systems of collaborators), proper e-design system environment including interoperability among CAD tools, analysis tools, data, can be customized. It should be noted that additional tools and functions can be appended by client request.

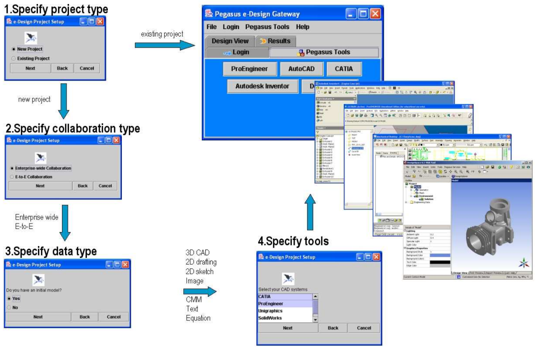
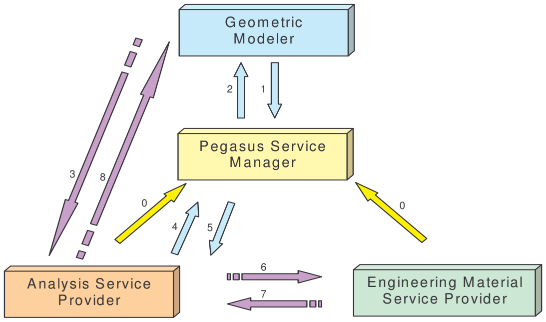


Figure 8: e-Design project customization

For different collaboration scenarios, the e-Design environment should provide transparent views to both stakeholders and e-tools. That is, e-Design stakeholders have uniform functional views of e-Tools without notification of physical locations. And e-Tools can provide services without imposing system-dependent restrictions to stakeholders. Services are based on interoperable network and application protocols without implementation restriction during the system's evolution. Information flow process within the e-Design environment should be designed from the viewpoints of efficiency and security besides transparency. Lean information exchange should be supported among heterogeneous tools considering the limitation of communication bandwidth. Protection of Intellectual Property is vital to build a trustable cyberspace for product development.

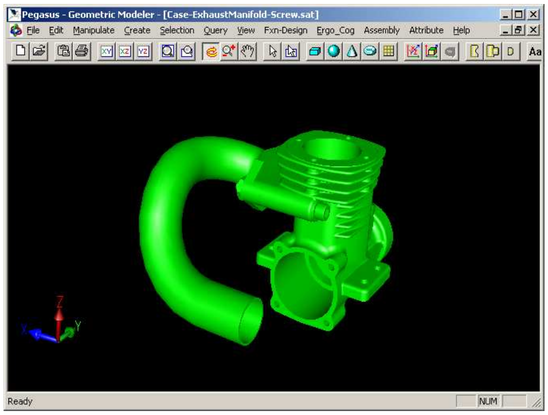
To illustrate the service architecture of Pegasus system, a demonstration is described in this section. Figure 9 illustrates a typical assembly design cooperation in the Pegasus service architecture between the Pegasus service manager, a geometric modeler, an analysis service provider, and an engineering material service provider. The various Pegasus component implementations for Figure 9 are shown in Figures 10 to 13.



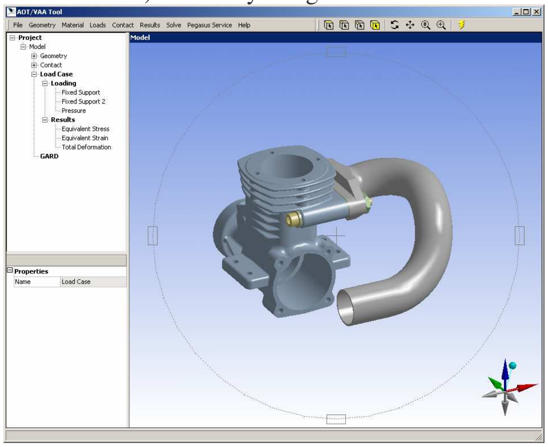
No.	Description
0	Service providers register services at Service Manager.
1	Geometric Modeler looks up analysis service.
2	Geometric Modeler receives the provider's information of analysis service.
3	Geometric Modeler requests analysis service from Analysis Service Provider.
4	Analysis Service Provider looks up material service.
5	Analysis Service Provider receives the provider's information of material service.
6	Analysis Service Provider requests material service from Engineering Material Service Provider.
7	Analysis Service Provider receives material service.
8	Geometric Modeler receives analysis service.

Figure 9. Assembly design cooperation

In this assembly design example, the Geometric modeler (Figure 10-a) provides detailed design services (such as sketching, feature generation, assembly design, etc.) for design engineers. Assuming the designer want to join the an exhaust manifold and an engine case by mechanical fastening, the designer should know the physical effects, such as deformation, bucking, stress/strain distribution on the assembly. Once the designer indicates a certain joining method (in this case a mechanical fastener), a virtual assembly analysis tool (Figure 10-b), which is a tool of the Geometric modeler, is automatically triggered and it generates analysis parameters based on the assembly design information. The assembly design information has been imposed on the design model by the system and the designer does not need to know any details about this translation. The virtual assembly analysis tool is a simple interface to show the analysis model and to be confirmed by the designer, and is linked to the assembly design cooperation network (service-oriented architecture). The physical effect can be simulated by use of mechanical analysis service. This mechanical analysis service, which is provided by analysis service providers, such as ANSYS, ADINA, and ABAQUS, can be invoked remotely through the Pegasus service manager (Figure 11). To accomplish this analysis, the Analysis service provider (Figure 12) needs the joining parameters and material properties. The material properties, which are sometimes but essential for engineering design, can be provided by engineering material service provider. An Engineering Material service provider (Figure 13) offers engineering material lookup services.

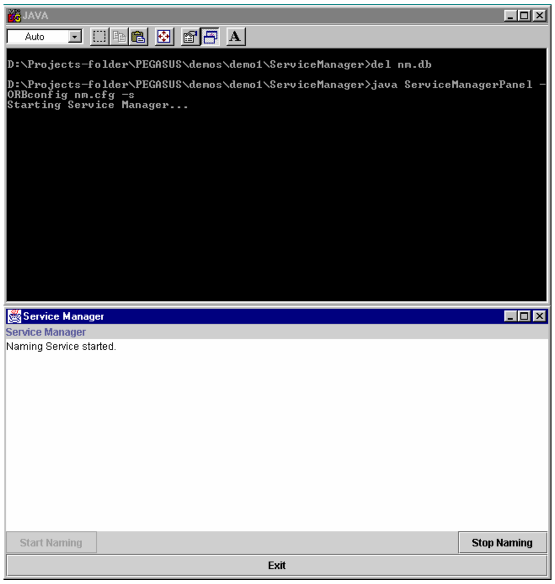


a) Assembly design modeler



b) Virtual assembly analysis tool

Figure 10. Geometric modeller

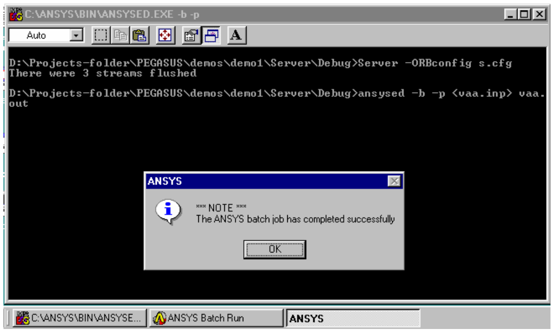


```
D:\Projects-folder\PEGASUS\demos\demo1\ServiceManager>del nm.db

D:\Projects-folder\PEGASUS\demos\demo1\ServiceManager>java ServiceManagerPanel -
ORBconfig nm.cfg -s
Starting Service Manager...
```

Naming Service started.

Figure 11. Service manager



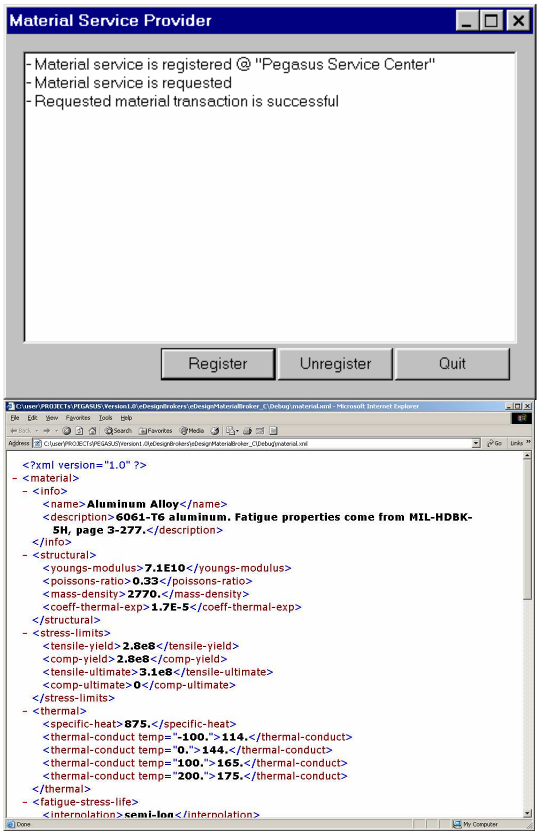
```
D:\Projects-folder\PEGASUS\demos\demo1\Server\Debug>Server -ORBconfig s.cfg
There were 3 streams flushed

D:\Projects-folder\PEGASUS\demos\demo1\Server\Debug>ansysed -b -p <vaa.inp> vaa.
out
```

ANSYS

*** NOTE ***
The ANSYS batch job has completed successfully

Figure 12. Analysis service provider



- Material service is registered @ "Pegasus Service Center"
- Material service is requested
- Requested material transaction is successful

Address: C:\user\PROJECTs\PEGASUS\Version1.0\eDesignBrokers\eDesignMaterialBroker_C\Debug\material.xml

```
  <?xml version="1.0" ?>
- <material>
  - <info>
      <name>Aluminum Alloy</name>
      <description>6061-T6 aluminum. Fatigue properties come from MIL-HDBK-
        5H, page 3-277.</description>
    </info>
  - <structural>
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      <poissons-ratio>0.33</poissons-ratio>
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```
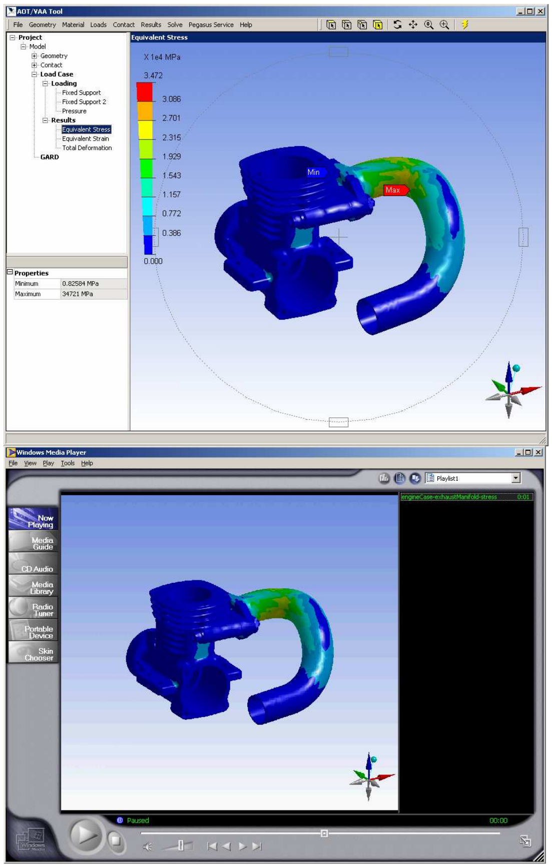

Figure 13. Engineering Material service provider

In order to perform a realistic simulation of the physical effects of the joining operations, the analysis service provider (transparent to the Geometric modeler) looks up and acquires the material information on the specified material type from the Engineering Material Service Provider. Remark that the Geometric modeler provides only material type and design configuration. When the analysis is completed, the Analysis service provider returns the analysis results (e.g., output files, animation movies) to the virtual assembly analysis tool (Figure 14).

The locations of various service providers are not known until at run-time. The relation between the service consumers and the service providers is built dynamically. This relation can be viewed as a service chain, which connects service provider with client/server affiliation, as illustrated in Figure 15.

The Service manager plays an important role in this service chain management. It allocates service resources according to service consumers' demand and service providers' capability and capacity. In a more matured system, it is possible that several providers can offer same services. Thus when Service Manager makes decisions, some other factors (geographical location, capacity, compatibility level, etc.) will be considered.



Properties

Minimum	0.82584 MPa
Maximum	34721 MPa

Figure 14. Analysis service response

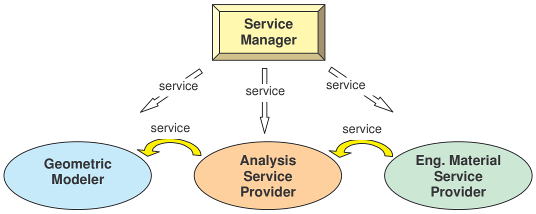


Figure 15. Service chain relations

6. CONCLUSION

This paper addresses the concept of a new design paradigm, e-design, enabling seamless and dynamic integration of distributed design objects and engineering tools over the Internet. In order to shorten product development life-cycle, and consequently reduce overall cost, an open system for ease of collaboration is needed. The openness provides required extensibility, portability, interoperability, and scalability. In this paper, a service-oriented open architecture is introduced to conceptualize a future e-design environment, which allows cost-effective distributed design collaboration. The *e*-design environment transparently integrates overall product life-cycle management activities, including conceptualization, detailed design, virtual simulation and testing, and supply chain management. Various requirements to realize future e-design systems for different collaboration scenarios are described.

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Annex1:

Table 1 The requirements of e-Design infrastructure for collaborative design

Interoperability from CAD to CAD, from CAD to CAE, from CAE to CAE	Multidisciplinary design in Product Lifecycle Management	Multidisciplinary constraints & preferences capture	Lean product data management, instant access & visualization	Proactive analysis & transparency	Virtual simulation & prototyping	Security and trust management
• Standards and protocols supplement • Parameters and constraints representation • Non-geometric constraints capturing design intents	• System engineering approach • Conceptual design (functionality-based, ergonomics & cognitive-based)Direct constraint imposition • Conflict resolution & management • Design activity based cost modeling • Multi-attributes decision models • Reliability matrix • Computationally efficient, high-fidelity predictive models	• Multidisciplinary constraints & preferences representation and management • Multidisciplinary constraints representation & multi-objective decision making • Conflict resolution • Material representation methodology	• Lean product data modeling • Subscription-based hybrid data modeling • Distributed data linkage mode • Multi-views with different levels of details	• Capacity for process of analysis, etc, “behind the scene” at remote locations without setup • High level modeling knowledge capturing in Engineering Analysis Modeling • Domain specific analysis knowledge modeling & ontology Model reusability, adaptability, and interoperability • Open system architecture	• Development of Physics-based models • Virtual reality, product, environment models for system level simulation • Models for simulation-based design under uncertainty • Virtual collaboration and sharing • Virtual assembly analysis, design, and knowledge capturing • Simulation-based acquisition • Real-time visualization	• Security and trust modeling • Trust for service for distributed, enterprise-wide e-Business networks • Trust issues concerning honestly, openness, reliability, competence and benevolence • Trust-support infrastructure