NETWORK-CENTRIC PRODUCT REALIZATION AND THE ROLE OF STANDARDS

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Abstract

The early part of this millennium has witnessed the emergence of an Internet-based engineering marketplace. Here, engineers, designers, and manufacturers from small and large companies can collaborate electronically in various product development and marketing activities. These capabilities are being enhanced by a new manufacturing software environment comprised of a network of cooperating engineering applications. These applications include multi-media tools and techniques that facilitate collaboration between geographically distributed applications and virtual reality tools that enable visualization and simulation in a synthetic environment. In this paper, we provide an overview of a network-centric design and manufacturing environment, followed by discussions on the role information exchange standards play in the seamless interoperation of these tools and dynamic composition of engineering applications and services.

1. Introduction

Twentieth century manufacturing was heralded by the Henry Ford's introduction of mass production or production-driven manufacturing. This radically changed automobile manufacturing and society, which went from custom-made, expensive cars for the few to standardized, affordable cars for all. It also changed the way everything else was manufactured so that all manufactured goods became affordable for a large segment of society. This new way of manufacturing was based on standardization, which allows independent fabrication of components that get assembled to create the final product. Eventually, this new standardized approach to manufacturing was exported and established in other countries. In this first phase of globalization, manufacturing companies – called Original Equipment Manufacturers (OEMs) - had vertically integrated production lines, usually co-located, to exploit economies of scale. These companies often built the same products irrespective of the needs and social preferences of the customer base.

A second globalization phase began toward the end of the last century. This phase was driven by the emergence of worldwide transportation and telecommunication infrastructures. The transportation infrastructure, which facilitated the movement of people and goods, appeared because of the massive innovations in commercial aircraft, giant cargo ships, and intercontinental railroads and highways systems. The communication infrastructure, which facilitated the movement of information and knowledge, appeared because of the wide dissemination of inexpensive computer technology and network communications hardware and software.

The impact of these infrastructures on manufacturing has been profound. First, the co-location of vertically integrated production lines has virtually disappeared. Component fabrication and subsystem assembly is now distributed across the globe to leverage the competitive advantages - labor costs and availability of raw materials, to name a few - of different countries. OEMs have become subsystem integrators, doing the final assembly frequently in the countries where the final products would be sold.

A major by-product of this new globalization has been the shift in the economic status of many countries. Formerly part of the non-industrialized world, these countries have dramatically increased their demands for products and services. More importantly, as the people in these countries acquire more economic power, they want those products and services customized for their wants and needs. These so-called mass customization requirements have further accelerated outsourcing and off-shoring. Hence, this phase can be viewed as customer-driven manufacturing. However, this acceleration includes not just fabrication and sub-assembly; it now includes engineering and design. This has spawned the need for a network-centric environment of cooperating engineering applications. These software applications include multi-media tools and techniques that can enhance closer collaboration between geographically distributed groups and virtual reality tools will allow visualization and simulation in a synthetic environment. The cooperation is achieved using information exchange standards that facilitate seamless interoperation of these heterogeneous applications. Additionally, the advent of service oriented architectures (see “SOA Approach to Enterprise Integration for Product Lifecycle Management,” which is available on the Web under the following URL: http://www.redbooks.ibm.com/), has provided practical ways for a network of engineering services to be dynamically composed aiding in the third globalization phase – network-driven manufacturing, which can be realized through virtual manufacturing networks.

In the following sections, we will provide a schematic of network-centric computer-aided production realization, followed by a discussion on standards and virtual manufacturing networks to understand the various interactions and standards in a networked enterprise. Additionally, we discuss the use of service oriented architectures for dynamically composing engineering services.

2. Networked Enterprises

A schematic of a network-centric computer-aided product realization (CAPR) system is shown in Figure 1. CAPR refers to the collection of business processes that cover the full lifecycle of the product from the earliest ideation to the final disposal. CAPR consists of many networks: design, production, distribution, etc. In this section, we provide a brief overview of the design network; other networks shown in the figure have similar components. The components of the design network, shown in the Figure 1, can be broadly classified into: engineering design services; repositories; and network infrastructure.

2.1 Engineering Design Services

Various computer support tools and services can be used in different phases in engineering design. Representative tools are discussed below.

*Engineering Specifications***.** In this phase, customer requirements are mapped into engineering requirements taking into account relevant laws, regulations, patents, and product standards, among other things. The quality function deployment (QFD) tool can be used to achieve such a mapping.

Traditional CAD. Computer Aided Design (CAD) systems were created to automate the creation and maintenance of 2D drawings. Their main goals were to save man-hours and increase the throughput of the drawing office. Even though they succeeded, they only aided in generating geometric forms, which often resulted in non-optimal designs.

Knowledge-based CAD. To overcome this drawback, knowledge-based CAD tools were developed. These tools help designers to reason about the product in terms of its intended functions first. In this way, its form can be generated subsequently from those functions. Put another way, these knowledge-based design/synthesis tools first focus on the symbolic structure of design and later assist the designer in mapping from that symbolic structure to a specific geometric model.

Immersive CAD. Immersive CAD tools enable humans to become "part" of the design. These tools include virtual displays, haptic devices, visual and speech interfaces. They can aid in the evaluation of the operability and manufacturability of proposed designs. Some allow direct modification of designs based the experience gained in manipulating the virtual prototype.

Analysis/Simulation. Computer-aided engineering (CAE) analysis tools, such as kinematic, finite element and computational fluid mechanics analyses, focus on the analysis and evaluation of the behavior of the designs.

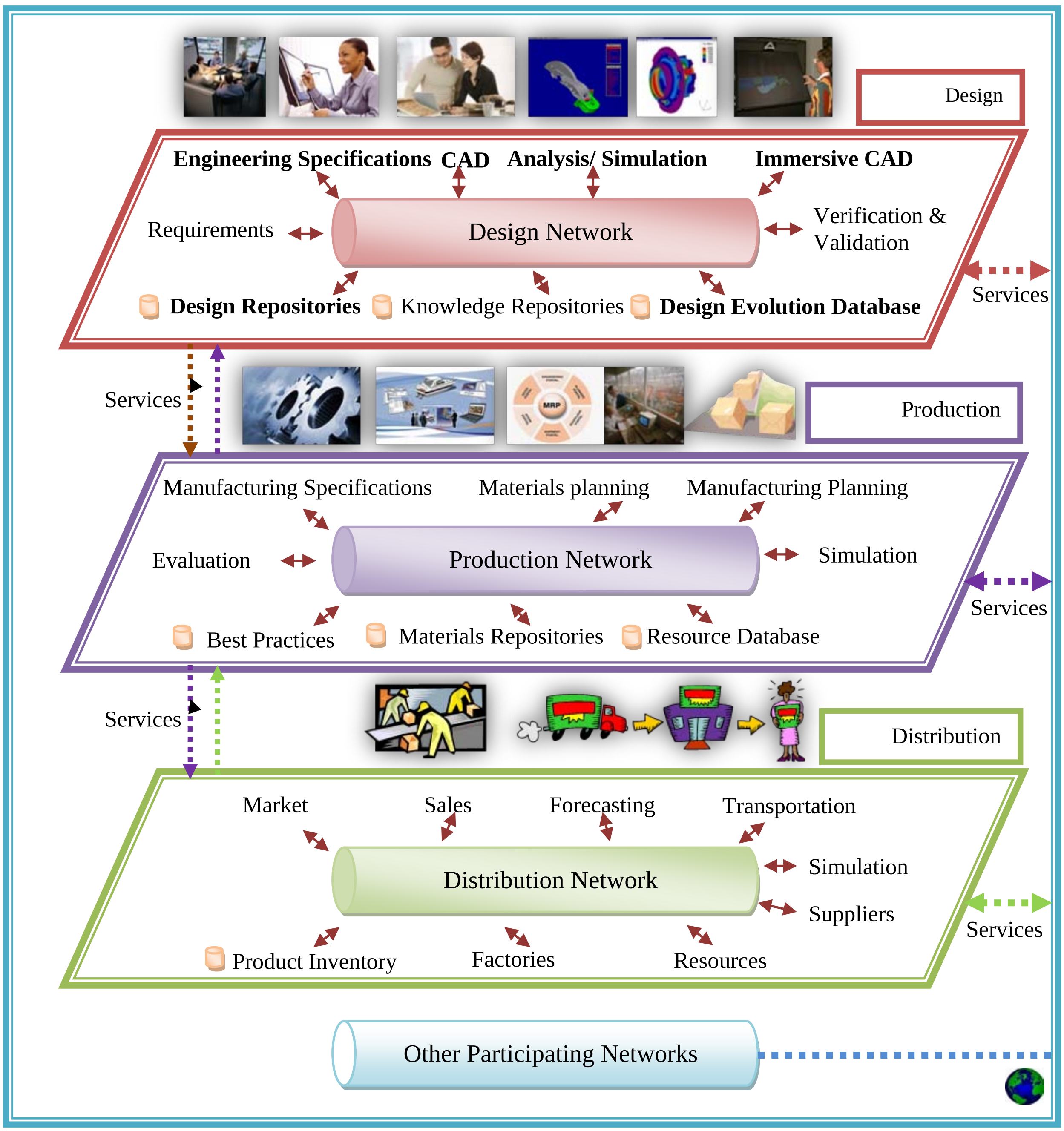

Figure 1 Network-Centric Computer-Aided Product Realization

2.2 Repositories

Several types of repositories including catalogs, regulations, evolutions, related designs, and product data management systems are used during the design process. We describe two representative repositories below.

Design Repositories. Design repositories are electronic filing cabinets where information on past designs is stored. The type of information stored varies considerably from one company to another. Drawings, 3D modes, design rationale, bills of materials, components hierarchies, and assemblies are some examples of such information. This information is stored in a form suitable for browsing and retrieval for direct use in the active design process.

Design Evolution Repositories. Typically, several candidate designs are created before the final design. These different versions represent a historical evolution. That evolution together with all relevant documentation is captured in a design evolution repository. In rare cases, the entire repository will reside physically in a single database. More frequently, it will reside in multiple databases distributed across the world. In either case, the database management system must present every user with the information needed in the format desired. This may necessitate syntactic as well as semantic translations of information passing to or from the database.

2.3 Network Infrastructure

The network infrastructure includes all the components required to support the physical exchange of information between these repositories and the software applications that create, modify, and use that information. Those applications are dominated by traditional geometry-based CAD and the CAE. Although knowledge-based CAD gained some visibility in the early 1990s, its impact is yet to be realized. Product data management (PDM) systems provide some of the functionalities of design evolution databases. These PLM systems are gradually being replaced by Product Lifecycle Management (PLM) systems, and in the future Sustainable Lifecycle-based Information Management (SLIM) systems. Currently we are witnessing a transition of the connections of the design network to other networks (e.g., production) from rigid to collaborative to dynamically composable.

3. Typology of Standards for a Networked Enterprise

Networked infrastructures guarantee the physical exchange of information; they do not guarantee a meaningful exchange of that information. In other words, they do not guarantee both syntactic and semantic interoperability of the applications that use that information. For this, we need several types of standards.

3. 1. Exchange standards

Exchange standards define concepts, such as a product models, purchase orders, invoices, production orders, process plans, schedules, and so on. For this paper, the most important of these is product models. The most common product model standard is STEP (Standard for the Exchange of Product model data) or ISO 10303. STEP, which is an international standard deals mostly with geometric data. A number of so-called application protocols have been added to this geometry data to provide a more comprehensive product model. The NIST work on a core product model (CPM) and its various extensions provide a strong semantic foundation. A similar effort is the ESPRIT funded project MOKA (Methodology and tools Oriented to Knowledge-based engineering applications). Both NIST and MOKA efforts use the UML information model standard (see next section).

For representing manufacturing processes, NIST has led the development of the Process Specification Language (PSL) standard. Like product data, process data is used throughout the lifecycle of a product. This effort uses first order logic and OWL-like representations for its modeling. PSL can also be used for representing business processes.

SysML is an effort directed towards the specific domain of Systems Engineering. SysML is derived from the basic UML to cover the requirements, structure, behavior, parametrics, and the relation of structure to behavior (allocation). SysML reuses a subset of UML 2.0 diagrams and augments them with some new diagrams and modeling constructs appropriate for systems modeling.

A sample set of standards for the engineering product lifecycle is shown in Figure 2.

3. 2. Information/knowledge modeling standards

The information contained in these exchange standards is represented using a variety of information modeling languages. A number of standards governing the proper use of these languages exist. Commonly used information modeling include EXPRESS, EXPRESS-G, XML-Schema, and UML.

Recently, more semantically rich modeling languages, based on different forms of logic, have been developed through the W3C consortium and other bodies. These include standards such as KIF, OWL and RDF that support reasoning. This reasoning is expected to aid the process of semantic interoperability.

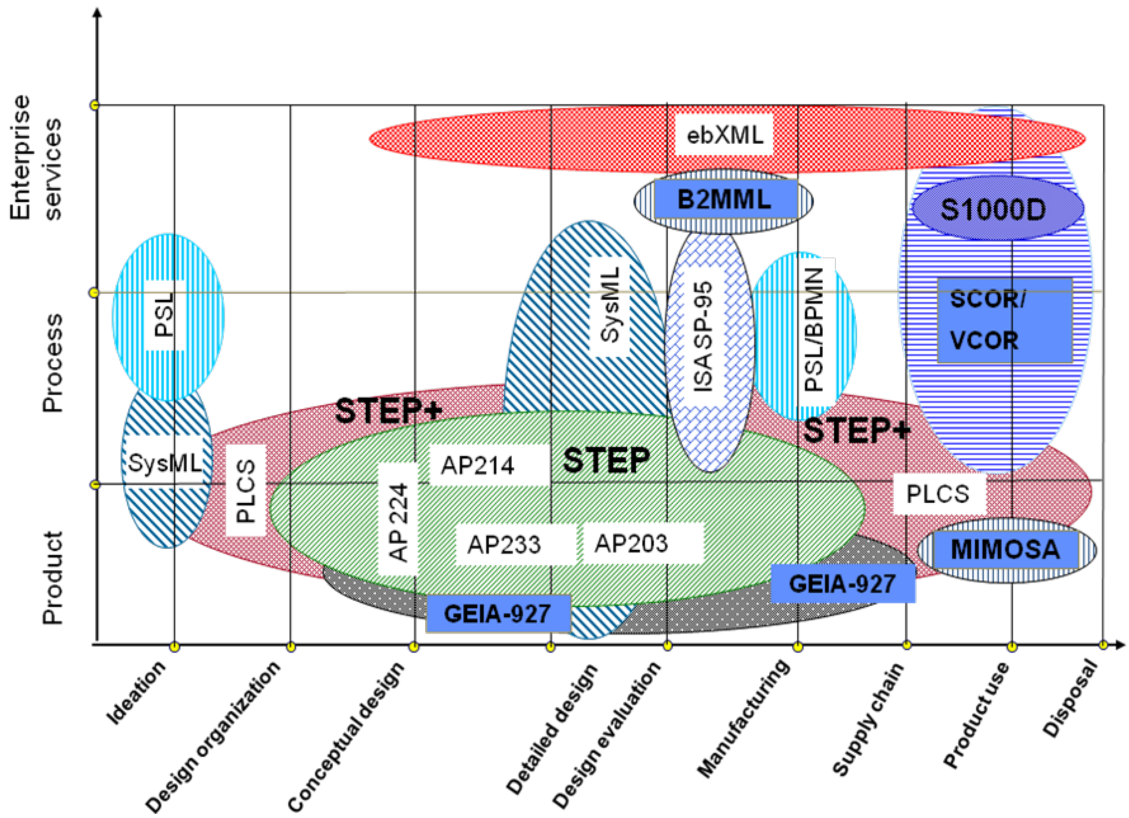

Figure 2: Representative Standards for Product Lifecycle

3. 3. Information interface standards

The actual exchange of information is normally achieved using a variety of mechanisms including file exchange, procedure calls, and messaging. Today, messaging is by far the most common of these mechanisms; and, there are many standards in place that define how this messaging is supposed to take place. Web services, proposed by W3C, are an emerging mechanism for exchanging information. W3C has also proposed standards for composing these services and using them in a service oriented architecture (SOA).

4. Virtual Manufacturing Networks

Organizational structures for manufacturing companies have also undergone a dramatic change over the last twenty years. The rigid, dedicated, and hierarchical structures typical of the second phase of globalization are giving way to highly dynamic collaborative partnerships. These partnerships will develop rapidly by composing global design and manufacturing resources in response to open market opportunities; and, disband just as rapidly when those opportunities disappear. These partnerships form the basis for the third phase of globalization, which we call network-driven manufacturing, which can be realized through virtual manufacturing networks. As earlier noted, information exchange will be critical to the success of these virtual networks.

4. 1. Information exchange in Virtual Manufacturing Networks

Information exchange is critical for collaborations and management at every phase of the product lifecycle. As noted, these exchanges currently take place through numerous message-based transactions between the various partners. The granularity and complexity of the information exchanged depends on the type of transaction and the specific partners involved. In these virtual networks, specific partners will not always be known in advance; but, the roles they will play will be known. Examples of roles include designer, manufacturer, and transporter. Additionally, the type of transaction will be based on (1) an agreed upon understanding of the business process being executed and (2) the roles played by potential partners in that business process. Tables 1 and 2 present an example of this notion of roles. The transactions, which are numbered based on an implied business process, are modeled as an information flow diagram in Figure 3 and as an interaction diagram in Figure 4. Once the transactions are determined then we can identify the various standards (see Figure 2), including pragmatics associated with implementations, associated with these transactions. For example, for transactions T5, T6, and T7 one might use AP 203, AP 224, and various semantics-based standards (e.g., MOKA, CPM) to encode design information.

Table 1: Participants in the strawman interaction model

Code	Description
S1	Client
S2	Designer
S3	Manufacturer
S4	Locator

Table 2: The transactions between the participants

Code	Description	From participant	To participant
T1	Designer criteria	Client	Locator
	Designer alternatives	Locator	Client
T2	Client-Designer negotiation*	Client	Designer
	Designer approval	Client	Locator
T3	Initial client specs	Client	Designer
	Design proposal	Designer	Client
	Design approval*	Client	Designer
T4	Manufacturer criteria	Designer	Locator
	Manufacturer alternatives	Locator	Designer
T5	Manufacturer negotiation*	Designer	Manufacturer
	Manufacturer approval	Designer	Locator
T6	Manufacturing specifications	Designer	Manufacturer
	Manufacturer feedback/counterproposal	Manufacturer	Designer
	Manufacturing approval*	Designer	Manufacturer
T7	Product completion notice	Manufacturer	Designer
	Product approval*	Designer	Client
T8	Product delivery	Manufacturer	Client

	Product acceptance*	Client	Manufacturer

*may involve multiple iterations

In this new environment, where systems are composed dynamically, the existing transaction-based approach may not be adequate for all information exchanges and all interactions. In the next section, we look more closely at this problem and the potential for using web services as (part of) the solution.

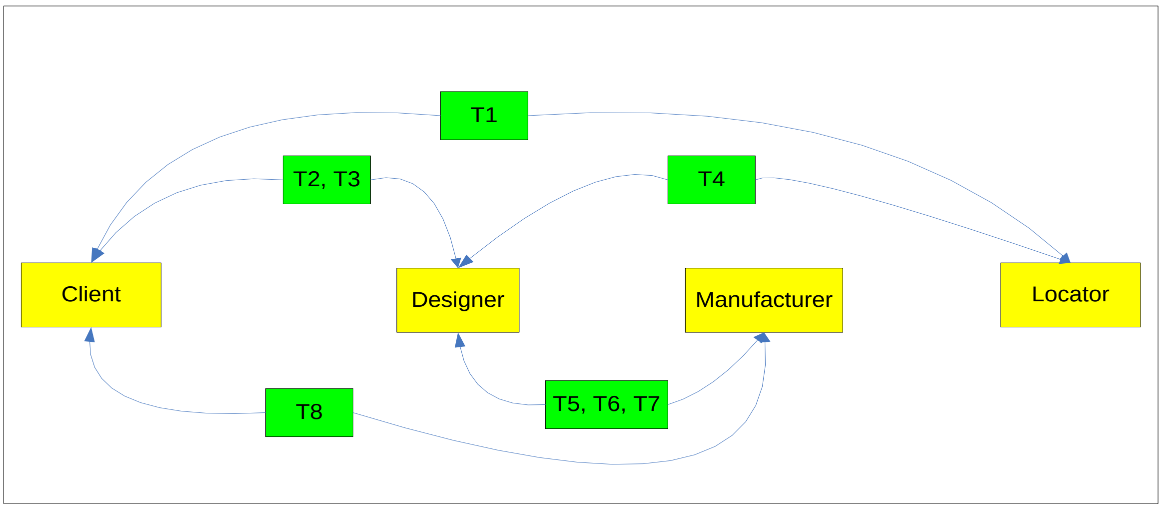

Figure 3 Strawman use case information diagram

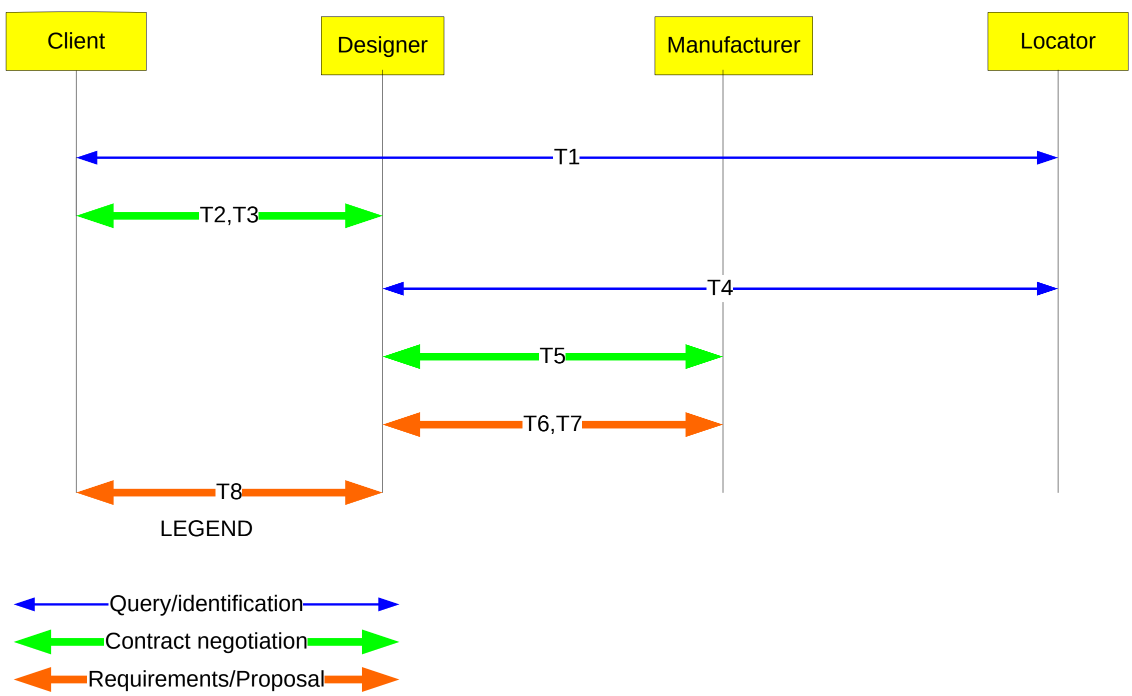

Figure 4 Strawman use case interaction diagram

4. 2. Composable Virtual Manufacturing Networks

In the future, as noted, manufacturing networks will be dynamically created from global resources where orchestration, cooperation, coordination, and distributed decision-making will be critical to their success. The execution of these functions, in turn, will depend on the creation of a communications infrastructure that automates, as much as possible, the exchange of required manufacturing- and business-related knowledge. To address this problem, we propose a new type of virtual information exchange infrastructure called Manufacturing Information Network (MIN) (see Figure 5). A MIN is based on the notion of web services. It is virtual, in the sense, that a MIN is composed every time an application needs to find or exchange information.

The concept of service oriented architecture (SOA) is critical to our idea. SOA is a software development paradigm in which information and applications are designed, implemented, and deployed as individual service units. These service units can reside anywhere in cyberspace. They can be invoked using standard protocols defined by W3C and combined to solve complex business problems. There are many benefits for adopting SOA in information systems. The "plug-and-play" capability of these service units allows convenient and flexible reconfiguration of system functionalities. Furthermore, the system can be divided into modules for development and maintenance, allowing a large complicated system to be built in a scalable manner.

Conceptually, the Manufacturing Information Network will constitute another "layer" of open cyberspace, sitting atop the Internet and other evolving Web technologies. As such, it will be independent of particular enterprise software applications. Such an infrastructure will enable the complete virtualization of and ubiquitous access to global manufacturing resources allowing information to be exchanged anywhere, anytime, on any device. The primary feature of the Manufacturing Information Network is composability. Composability is a system design principle that deals with component inter-relationships. A high degree of composability means the system has recombinant components that can be selected and assembled in arbitrary ways to satisfy user requirements. A composable component must be self-contained (modular), self-descriptive and be able to integrate easily with other components in the system.

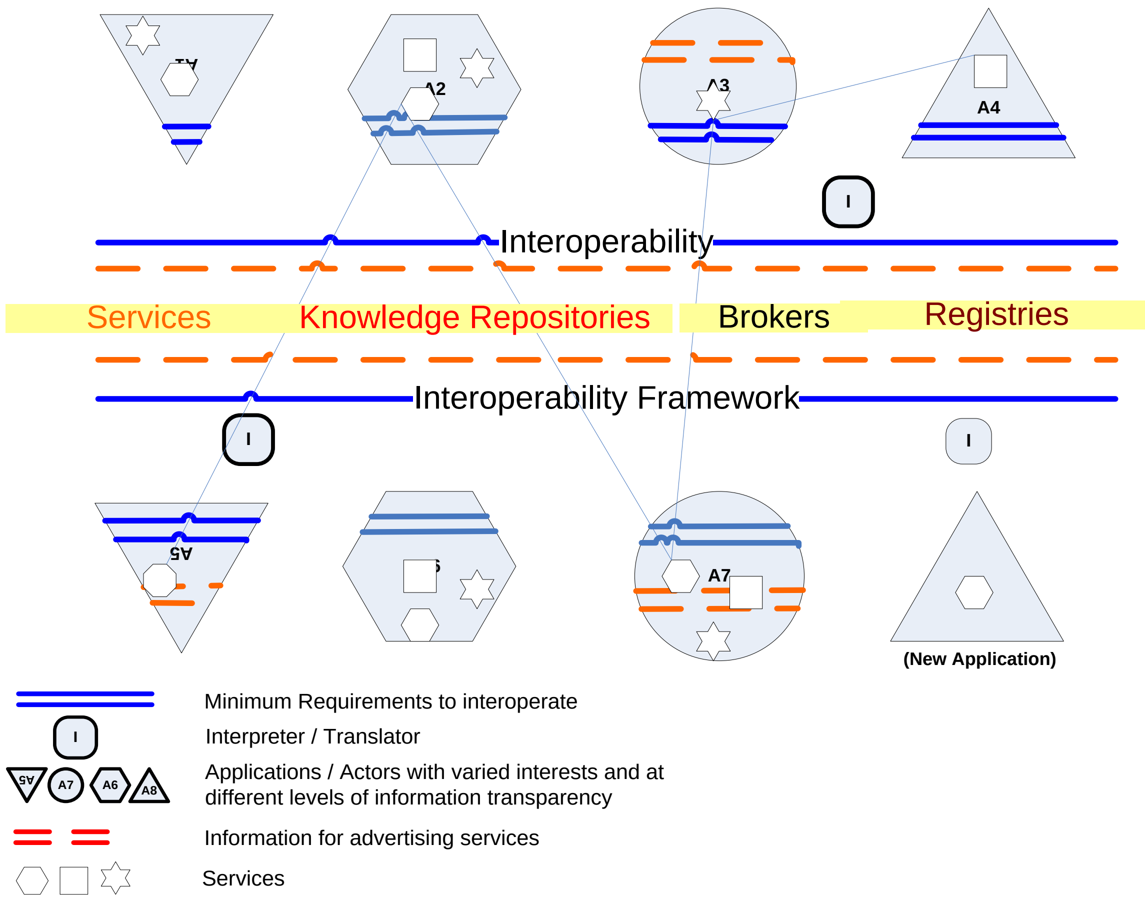

Figure 5 Composable-On-Demand Manufacturing Information Network

Services. The goal of the services is to be discovered and used as frequently as possible and by, for the most part, unknown actors (Applications or Engineering Services). A service must be engineered for interoperability and designed to live in a completely open environment. This means, at a minimum, they must publish complete (register with the Service Registry), semantically rich descriptions and representations of what they do (their capabilities), the information they need to do it (their inputs), and the information they provide when they are done (their outputs). Ultimately, if the descriptions and representations are not easily understood, a service will not get used. In addition to engineering services, a number of different services are envisioned. These services

- facilitate real-time information sharing and collaboration between enterprises, such as reasoning, searching, discovery, composition, assembly, and delivery of semantics automatically
- leverage emerging Web technologies for enabling a new generation of information-based applications that can self-compose, self-declare, self-document, self-integrate, self-optimize, self-adapt, and self-heal

- support knowledge creation, management, and acquisition to enable knowledge sharing between virtual organizations
- help connect islands of interoperability by federating, orchestrating, or providing common e-business infrastructural capabilities such as digital signature management, certification, user profiling, identity management, and libraries of templates and interface specifications
- support the use of mashup technologies such as verification of credentials; reputation management; assessment of e-business capabilities; assessment of collaboration capabilities; facilities for data sourcing, integrity, security and storage; contracting; registration and labeling; and payment facilities, among others

Knowledge Repositories. Knowledge Repositories, such as the design repositories described earlier, to the success of SOA, in general, and our notion of MIN, in particular. Services browse and will query these repositories for both structured and unstructured information. This requires semantically rich metadata to be developed and posted to registries. Registries (or Locators) can be thought of as advertisement services or a yellow book. They are also critical to a successful implementation of brokers.

Brokers. Brokers provide what is sometimes called bureau services. Depending on the demand and request, the broker identifies the service component that fills the need, locates it, and plugs it into the framework. The broker’s function is to select and assemble components belonging to different applications into integrated processes; for example, for order fulfillment.

4. 3. Research issues

We have identified the following research issues, which must be resolved before our ideas can be implemented successfully. NIST is working to resolve many of these issues.

- specific roles of virtual manufacturing framework components like brokers, service registry, will have to investigated as part of the framework
- minimum requirements for an application/service to participate in a manufacturing network (for service provider and service requester)
- level of information transparency required to participate
- roles of an interpreter/ translator for new application services
- common vocabulary (ontology) requirements for interoperability, including additional terminologies introduced by sustainable enterprises
- level of intelligence that will make these application systems adaptive and self configuring (implies an application to be either context-aware, adaptive or anticipate based on experience)

- specific use cases of manufacturing and business processes (scenarios or transactions)

5. Conclusion

This paper broadly discusses three phases of globalization – production-driven or mass production (sequential, rationalization of production), custome-driven or mass customization (variety, collaborative), and network-driven manufacturing (variety, collaborative composable on demand networks) – and the evolving role of information-related standards. Semantic interoperability is identified to be very important for robust information exchange. The paper also proposes a new virtual information exchange infrastructure called MIN, Manufacturing Information Network. MIN is based on the notion of web services and the concept of service oriented architecture. The paper ends with a collection of important research issues associated with the implementation of MIN.

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Certain commercial software systems may have been identified in this paper. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology (NIST); nor does it imply that the products identified are necessarily the best available for the purpose. Further, any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NIST or any other supporting US government or corporate organizations.

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