Towards Information Networks to Support Composable Manufacturing

Mahesh Mani
Design and Process Group
Manufacturing System Integration Division
National Institute of Standards and Technology
100 Bureau Drive, Gaithersburg, MD USA
(301) 975 -5219
mahesh@nist.gov

Albert. T. Jones
Enterprise Systems Group
Manufacturing System Integration Division
National Institute of Standards and Technology
100 Bureau Drive, Gaithersburg, MD USA
(301) 975 - 3554
albert.jones@nist.gov

Junho Shin
Enterprise Systems Group
Manufacturing System Integration Division
National Institute of Standards and Technology
100 Bureau Drive, Gaithersburg, MD USA
(301) 975 -3654
junho.shin@nist.gov

Ram D. Sriram
Design and Process Group
Manufacturing System Integration Division
National Institute of Standards and Technology
100 Bureau Drive, Gaithersburg, MD USA
(301) 975 -3507
sriram@nist.gov

ABSTRACT

Rigid, supply-chain organizational structures are giving way to highly dynamic collaborative partnerships. These partnerships will develop rapidly by composing global manufacturing resources in response to open market opportunities and they will disband just as rapidly when those opportunities disappear. Cooperation, coordination, and distributed decision-making will be critical to the success of these dynamically composable systems. That success, in turn, will depend on the creation of a manufacturing information network that automates as much as possible, the identification, formalization, encoding, and sharing of appropriate manufacturing- and business-related knowledge. In this paper we present some of the issues and requirements associated with the creation of such networks.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design- *Distributed networks.*

General Terms

Algorithms, Management, Performance, Design, Standardization, Languages

Keywords

Manufacturing information networks, interoperability, common vocabulary, standards, composable manufacturing

1. INTRODUCTION

For most of the 20th century, competitive advantage was defined by the production and labor capabilities of individual original equipment manufacturers (OEMs). In the mid 90s, OEMs sought to reduce production and labor costs by outsourcing those capabilities globally. Thus, the rigid supply chain structures of the past are slowly giving way to virtual supply networks of collaborative partnerships. These partnerships will develop rapidly by composing global resources in response to market opportunities and they will disband just as rapidly when those opportunities disappear. These resources now include designers, engineers, planners, transporters, suppliers, fabricators, assemblers, buyers, vendors, and service providers, among others. The only way to improve competitive advantage in such a networked system is to improve the orchestration of all of these resources so that they behave as if they were a single virtual factory.

A major concern in these networked systems is the availability of the right product, process, and business information when and where it is needed. We believe that this requires a separate integration infrastructure, which we call the manufacturing information network (MIN). A MIN will enable the discovery, coordination, and automated exchange of information regardless of where it resides in the system. The reason that discovery, co-ordination, and automated exchange is so important is that the system orchestrator must have (1) intimate, real-time knowledge of the capabilities and capacities of all potential partners (2) accurate predictions of customer demands and product requirements, (3) the ability to match supplier capabilities to those requirements, and (4) the skills to manage the entire, global set of production and delivery schedules.

In this paper we present our vision for a MIN, which is based on the concepts of the internet of services (IOS) and service-oriented architecture (SOA). The rest of the paper is organized as follows: Section 2 first presents the modeling of composable manufacturing systems followed by section 3 briefly discussing information exchange in composable manufacturing systems. Section 2 and 3 aim to present the diverse information exchange in MIN. Section 4 briefly presents the commonly used standards, reference models and business processes. Sections 5 and 6 present our proposed MIN approach and related research issues respectively. Finally Section 7 presents our conclusions.

2. MODELING COMPOSABLE MANUFACTURING SYSTEMS

Bringing complex products to customers requires close collaborations among a number of functions including design, engineering, manufacturing, and logistics. As noted above, these functions are performed by resources that are geographically distributed around the world. As described in [1,2] these resources are modeled frequently as autonomous, interacting software agents with each agent executing one function. Agents are implemented as intelligent web-based applications that wrap functional applications and manage electronic information exchange. The communications protocols used by these software agents have been developed by FIPA (Foundation of Intelligent and Physical Agents)[1], an IEEE Computer Society standards organization that promotes agent-based technology and the interoperability of its standards with other technologies. These simple protocols govern the information data flow through the participating agents, thus ensuring seamless data and information transfer. Their potential benefit is that the agents can exchange the same information as their real-world counterparts. The principal drawback is that they are not powerful enough to allow the agents to understand most of that information. Therefore, interoperability remains a major impediment for software agents, just like it does for their real-world counterparts.

3. INFORMATION EXCHANGE IN COMPOSABLE MANUFACTUING SYSTEMS

Information exchange is critical for collaborations and management at every phase of the product lifecycle. In current supply chains, these exchanges take place typically 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 partners involved. The type of transaction is based on an agreed upon understanding of the business process being executed (see section 4). This understanding is possible because (1) the partners are known in advance, that is the organizational structure is somewhat rigid and (2) the negotiation is dictated by the OEM, who sits at the top of a command/control hierarchy.

Several recent reports on the "Future of Manufacturing" predict two major changes in these supply chains [3,4]. First, OEMs' former command-and-control business model will evolve into more of a collaborative and negotiated partnership model. Second, the supply base will no longer be static and known in advance; rather, it will change regularly. In this new environment where systems are composed dynamically, the existing transaction-based approach will not be adequate for all information exchanges. Before describing the MIN approach, we briefly review some commonly used information standards and reference models governing message transactions and business processes.

4. COMMONLY USED STANDARDS, REFERENCE MODELS AND BUSINESS PROCESSES

A number of supply-chain Common Business Processes (CBP), information standards, messaging standards, and reference models have been defined. Some are industry specific and some are not. CBPs are industry neutral and re-usable business processes. Various components of a common business process specification can be re-used to create new business processes (See Figure 1]. Re-use will typically occur at the business process, business collaboration, business transaction, and business document model components.

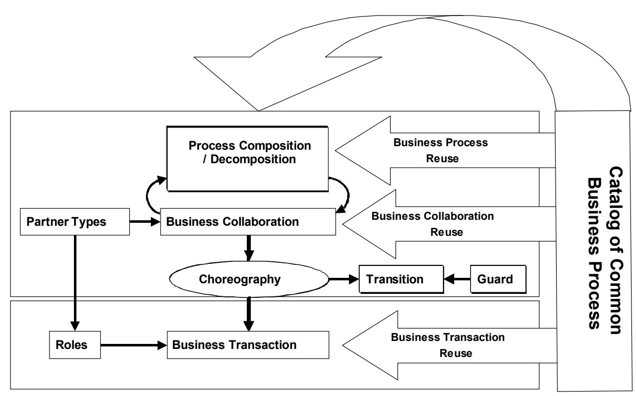

Figure 1. Catalog of Common Business Processes[2]

ANSI X12 (also known as ANSI ASC X12) is the official designation of the U.S. national standards body for the development and maintenance of Electronic Data Interchange (EDI) standards. X12 has an underlying syntax, which is an ANSI standard. Within that syntax, there are directories of data elements, composite data elements, segments, and messages. There are conventions for placing messages in an "envelope"

[1] http://www.fipa.org/specifications/index.html

[2] http://www.ebxml.org/specs/bpPROC.doc

which identifies the sender and receiver and other attributes of a transmission[3].

EDIFACT (Electronic Data Interchange for Administration, Commerce, and Transport (EDIFACT) is the international Electronic Data Interchange developed under the United Nations. EDIFACT has an underlying syntax, which is an ISO standard. Within that syntax, there are directories of data elements, composite data elements, segments, and messages[4].

EIDX represents the Electronics Industry Data Exchange Group. As part of the Computing Technology Industry Association (CompTIA), EIDX is committed to advancing industry growth through the development of standards, best practices, accreditations, professional education and development, tools and business solutions[5].

RosettaNet is an independent, self-funded, non-profit consortium dedicated to the development and deployment of standard electronic business interfaces. These standards form a common e-Business language, aligning processes between supply chain partners on a global basis. RosettaNet's Partner Interface Processes (PIP) allows trading partners of all sizes to connect electronically to process transactions and move information within their extended supply chains[6].

The Open Applications Group Integration Specification (OAGIS) is an effort to provide a canonical business language for information integration. It uses XML as the common alphabet for defining business messages, and for identifying business processes (scenarios) that allow businesses and business applications to communicate. Besides providing a comprehensive set of XML business messages, OAGIS also accommodates the additional requirements of specific industries by partnering with various vertical industry groups[7].

Table 1 presents possible mappings between several of these standards.

Table 1. Example mapping of common business processes

Common Business Processes	Normative Category	Normative Sub Category	EDIFACT including sub-sets	X12 including sub-set	RosettaNet Partner Interface Process	CII (HWSW 001A)	OAG BODs
Distribute Dispatch Instructions	**Procurement Management**	**Transportation and Distribution**	**INSDES**	**862, 858**	**PIP3B1**		**165_sync_shipschd_001**
Notify Of Advance Shipment	**Procurement Management**	**Transportation and Distribution**	**DESADV**	**856, 869**	**PIP3B2**	**0520**	**165_sync_shipschd_001**

Besides the above, SCOR and DCOR present process reference models for any supply chain.

[3] http://www.x12.org

[4] http://www.stylusstudio.com/edifact

[5] http://eidx.comptia.org

[6] http://www.rosettanet.org

[7] http://www.openapplications.org

SCOR: Supply-Chain Operations Reference is a process reference model that has been developed and endorsed by the Supply-Chain Council (SCC). The SCC is an independent, not-for-profit, global corporation with membership open to all companies and organizations interested in applying and advancing the state-of-the-art in supply and design chain management systems and practices. SCOR has been adopted as the cross-industry de facto standard diagnostic tool for supply chain management[8]. It is a hierarchical model that has five major building-block processes: plan, make, source, deliver, and return.

DCOR: The Design Chain Operations Reference-model (DCOR)[9]. The newest model from the SCC, the DCOR-model captures the SCC's Technical Development Steering Committee's consensus view of design chain management. The structure is based on the same hierarchical philosophy as SCOR, but with five different building-block processes: plan, research, design, integrate, and amend.

5. OUR APPROACH: MANUFACTURING INFORMATION NETWORKS (MINS)

As noted above, future manufacturing networks will be dynamically created from global resources (see Figure 2). 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 an infrastructure that automates, as much as possible, the exchange of required manufacturing- and business-related knowledge. We call such an infrastructure a manufacturing information network (MIN). A MIN (see Figure 3) is created every time an application needs to find or exchange information.

Conceptually, the MIN will constitute another "layer" of open cyberspace, sitting atop the Internet and other evolving Web technologies. As such, it will be independent of any 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 MIN 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.

The key to achieving this capability is to link these various components together in arbitrary ways to exchange the information necessary to meet business needs.

The primary components of the MIN include services, repositories, brokers, and registries (See Figure 2).

[8] http://www.supply-chain.org/cs/root/scor_tools_resources/scor_model/scor_model

[9] http://www.supply-chain.org/cs/root/scor_tools_resources/designchain_dcor/dcor_models

Services: The goal of the services is to be discovered and used as frequently as possible and by as many different actors. A service must be engineered for interoperability and designed to live in a completely open environment where they will not know who their potential partners will be in advance. 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.

A number of different services are envisioned:

- Services that facilitate real-time information sharing and collaboration between enterprises, such as reasoning, searching, discovery, composition, assembly, and delivery of semantics automatically.
- Services that 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.
- Services that support knowledge creation, management, and acquisition to enable knowledge sharing between virtual organizations.
- Services that 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.
- Services that 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.

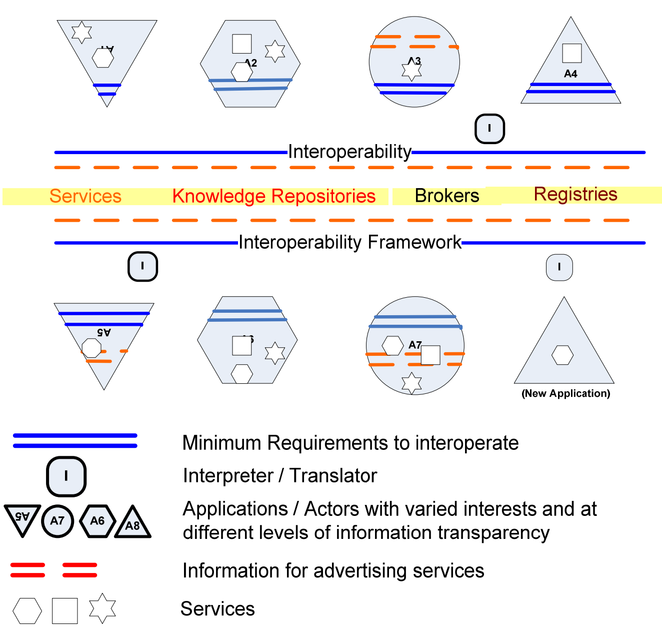

Figure 2. MIN Concept

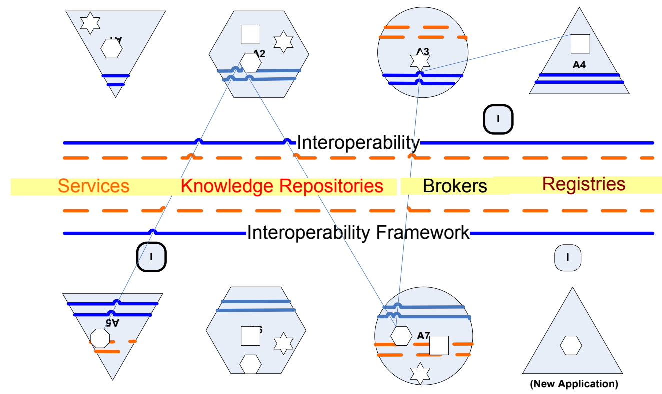

Figure 3. Composable-On-Demand MINs

Knowledge Repositories: Knowledge Repositories continuously capture, store, and analyze all manufacturing-related information, for example, the knowledge of assets, manufacturing facilities/ capabilities of an organization or enterprise. Participating applications can then query or browse both structured and unstructured information in order to retrieve and update information. Besides being dynamic, knowledge repositories must cater for explicit form of knowledge to be able to retrieve context sensitive data.

Brokers: Brokers can also be referred to as the MIN infrastructure 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. This integration is analogous to the formation of virtual enterprises from separate enterprises. Component technology provides seamless communication between applications residing in the different supply-chain partners.

Registries: Registries can be thought of as advertisement services or yellow pages. They can also be useful to locate knowledge repositories and services.

6. RESEARCH ISSUES

To address the development of the above discussed composable MIN and its corresponding infrastructure, we need structured research into the conditions/requirements for interoperability in these networks. The following research questions will have to be investigated:

- an interoperability framework in the context of MIN
- specific roles of a MIN component like brokers, services, registries, will have to be investigated as part of the MIN
- minimum requirements for an application to participate in MIN (for service provider and service requester)
- level of information transparency required to participate in MIN
- roles of an interpreter/ translator for new application services

- common vocabulary requirements for interoperability
- level of intelligence that will make these application systems adaptive and self configuring (implies an application to be either context-aware, adaptive or anticipated based on experience)
- specific use cases of manufacturing and business processes (scenarios or transactions)

There are undertakings at NIST to develop and demonstrate an open, standards-based, testing and integration infrastructure that enables the automated exchange of manufacturing information among suppliers [3]. This infrastructure will provide the foundation for the new types of collaboration and management described above as a number of NIST-supported economic impact studies claim that such an infrastructure does not exist today [4].

7. CONCLUSION

In this paper, we presented an approach towards information networks that supports composable manufacturing. We identified a need for a MIN infrastructure that provides a mechanism for information acquisition, sharing, delegation of tasks, and decision making between the various entities. We speculate on how the future of MINs may evolve as composable on demand MINs. Correspondingly we presented and discussed the issues and prerequisites that need to be addressed to support interoperability in such MINs.

Semantic interoperability may be the key to MINs of the future. Adopting semantic interoperability for product-process automates information flow in an extended enterprise among different levels of information resources. Future research is on composable MIN and architectures to enable the way manufacturing organizations use information technology (computers, networks, information systems, data, algorithms, and decision support) to make their manufacturing processes more effective.

8. ACKNOWLEDGEMENTS

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DISCLAIMER

9. REFERENCES

[1] Mahesh, M., Ong, S.K., Nee, A.Y.C., Fuh, J.Y.H., and Zhang, Y.F. 2007. Towards A Generic Distributed and Collaborative Digital Manufacturing. Robotics and Computer Integrated Manufacturing, International Journal of Manufacturing and Product and Process Development. 23, 3, (June 2007), 267-27. DOI=http://dx.doi.org/10.1016/j.rcim.2006.02.008

[2] Sriram, R.D. 2002. Distributed and Integrated Collaborative Engineering Design. Sarvan Publishers, Maryland.

[3] Li, M.S., Jones, A. 2008. An information infrastructure for next generation Global enterprises, International Multi-Conference on Engineering and Technological Innovation: IMETI 2008. Orlando. Florida. USA.

[4] Comparisons and Analyses of U.S. and Global Economic Data and Trends: Globalization: Trends and Impact Factors of Globalization of Manufacturing Input Factors on Future U.S. Manufacturing Capability. National Institute of Standards and Technology. U.S. Department of Commerce 2004. http://www.sri.com/policy/csted/reports/nist/NIST_SUBD_Globalization.pdf