The unification of robust enabling technologies of the Internet and ubiquitous access is resulting in market dynamics that change the way business is being conducted by electronic manufacturing services (EMS) providers. OEM/EMS enterprise relationships are no longer one-to-one or even one-to-many. Instead they are complex, distributed relationships in which many strategic partners, downstream suppliers and customers need to collaborate and share data in order to compete effectively. These new relationships, coupled with shrinking market windows and other dynamic market influences, have expiated the birth of the virtual enterprise or e-factory.

John Cartwright
Intel

Joanne Friedman
John Minchella
Celestica

Barbara Goldstein
NIST

Virtual Factory Project Tackles Integration

of Supply Chain Systems

While greater reliance on a supply network provides flexibility in response to unpredictable market conditions, the serious lack of standards for information integration among cross-company and inter-company systems can limit any potential efficiency gains. The National Electronics Manufacturing Initiative (NEMI) has created the Virtual Factory Information Interchange Project (VFIIP) to address some of the challenges of the emerging virtual enterprise or e-factory. Focusing on factory information systems (FIS) integration between OEMs and their EMS providers, the overall purpose of this project is to define standards which, when implemented, will reduce both the time and the cost required to establish and maintain information exchange partnerships across the manufacturing supply web.

Why Factory Information Systems?

Factory information systems form the nervous system of a manufacturing facility, analyzing data and delivering information to the machines and people who need it to make information-based decisions. These systems provide a bi-directional flow of information between the factory floor and the rest of the enterprise. Engineering work orders and component and product manufacturing data flow down to the factory; and product genealogy, defect rates, scrap, yields, utilization, process and other production related data are returned to the enterprise. Factory information systems do not process material. Instead, they collect and process the data used to process material efficiently. In the new e-factory model, this data flows to the enterprise and its strategic partners, downstream suppliers and customers.

The software applications employed throughout the manufacturing enterprise can be broadly classified into the following four categories:

• enterprise resource planning (ERP) systems, that provide the "front office" operations of an enterprise;

• manufacturing execution systems (MES), that provide real-time feedback on products progressing through a factory;

• shop floor control systems, that interact directly with equipment used to manufacture electronic products and their sub-assemblies; and

• equipment control systems, that are directly responsible for the real time control of equipment.

For the purpose of this discussion Factory Information Systems (FIS) are defined as being comprised of applications primarily within the MES and shop floor control categories, but which need to interface with or integrate data from applications within all four classifications, as illustrated in Figure 1 below.

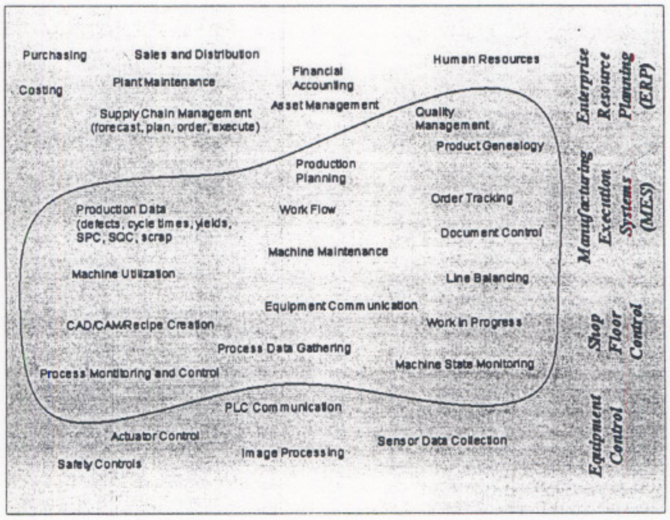

Figure 1. Factory information systems include the manufacturing execution systems and the shop floor control systems. In addition, these systems must interface with and integrate data from all of the systems within the manufacturing enterprise.

The Challenges of e-Factory Integration

In this rapidly changing environment, OEM product introduction may be significantly influenced by how quickly, how well, and where in the activity stream an OEM's information systems can be linked with those of their EMS suppliers. In effect, the earlier in the activity stream FIS systems can be interconnected, the more likely and positive the influence on the OEM's time-to-market window. FIS applications must thus interface to and integrate with systems outside the four walls of a single organization and into the manufacturing supply web.

Major manufacturers are outsourcing an ever larger proportion of their operations to first-tier suppliers. As a result, the EMS industry is growing at three times the rate of the electronics industry overall and, as OEMs contract with EMS providers for an increasing breadth of services, serious implications arise for factory information systems.

While greater reliance on a supply network provides flexibility in response to unpredictable market conditions, the lack of integration among cross-company information systems can limit the potential efficiency gains. Shrinking product life-cycles place extreme pressure on manufacturers to be quick to market with optimal product volume. In an environment where production is being outsourced at an increasing rate, rapid product introduction depends on quickly linking an OEM's information systems with those of their suppliers. However, most companies are still struggling to achieve effective integration of design and production functions within their own enterprises — a difficult task even when manufacturing is a captive activity. Such problems are amplified for the EMS, who must be able to accept designs produced by a variety of systems and return both product and formatted information back to their OEM customers.

In many cases, OEMs have their own proprietary ("home grown") systems which do not provide standard interfaces. Even when multiple OEMs share a common commercial tool, they typically customize it, resulting in output that is non-standard across implementations. One EMS provider reports that it maintains over 90 separate software translators to interpret customer design information.

To further exacerbate an already difficult situation, much of the rapid growth in the EMS segment is achieved through acquisitions. When an EMS provider buys another company, it is typically buying a whole new suite of (incompatible) software which it must integrate with the many disparate parts of its quickly growing enterprise.

Another issue is the ability to get real-time feeds from the factory floor. When an OEM is dealing with multiple EMS providers, each of which has its own proprietary "value add," it is difficult for the OEM to get meaningful data. This represents a whole new class of information that must move from one company to another, and there are no good standards for exchanging that data. Therefore, each partnership establishes a unique data transfer process which is not typically reused by other sets of companies.

Each partner in the production process must be sure they are working from the correct version of the product design, and that their software tools are consistently interpreting the information received. This is particularly challenging since the design usually lacks manufacturing details, is often not transmitted electronically, and when electronic, the information is typically sent in a combination of formats, which vary in terms of richness and ease of interpretation. Most information exchange formats used are specific to various CAD and CAM systems, and don't capture the complete range of information needed. Neutral file formats may be easier to transfer; however, some of the current standards (such as Gerber) were never intended to cover the assembly area and can result in much of the design information being lost, requiring that the work be duplicated to recreate the data. Proprietary, product-specific formats are often richer but are not ubiquitous in terms of market penetration.

As more work is outsourced, the OEMs and EMS providers alike must come to grips with the many challenges to their information systems and their business processes. Greater reliance on EMS providers demands the use of open systems and emphasizes the need for robust industry-wide standards such as:

- machine interface standards,
- change collaboration and product data management (PDM) standards,
- supply chain communication standards,
- standards for exchanging data between factory information systems, and
- standards for exchanging data between ERP systems and the factory floor.

Virtual Factory Information Interchange Project

NEMI has formed VFIIP as an industry-led effort to define standards to support information exchange partnerships across the manufacturing supply web.

Work within the project is divided among four teams as follows:

Business Process Team

This team's task is to create an industry view of how the supply chain functions. Its goal is to understand and define the business processes used by OEMs, EMSes and

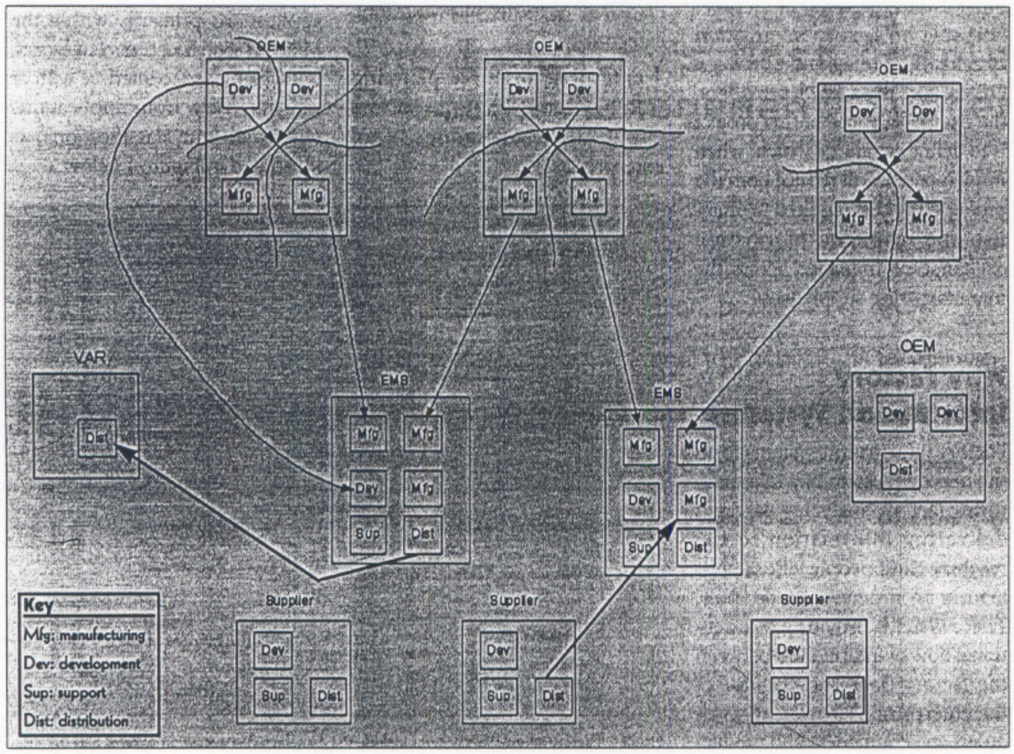

Figure 2. Through outsourcing, vertically integrated OEMs have redistributed their internal manufacturing capabilities to EMS providers. This group of companies – in some cases, competitors – must function together as a "virtual factory".

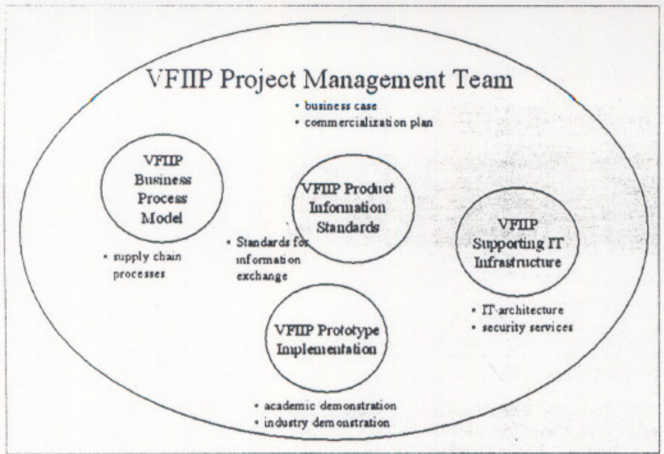

Figure 3. This figure shows the four Virtual Factory Information Interchange teams and the deliverables of each.

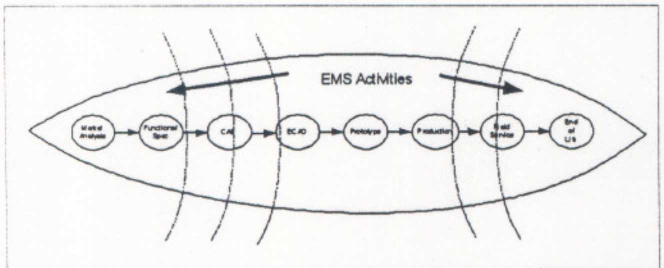

Figure 4. This figure shows some of the high level activities required of OEMs and EMS providers to bring a product to market. The dotted lines represent how the boundary between the OEM and the EMS (and supplier) may change over time. EMS companies are providing a growing number of services to their OEM customers, allowing the OEMs to concentrate on product development and marketing (i.e. their core competency and business).

suppliers to bring a product to market. The team will analyze the interactions within the manufacturing supply chain in order to develop a business case document that characterizes the nature of the industry as it moves toward outsourcing.

Product Information Standards Team

Whereas the Business Process team is identifying the interfaces between members of the supply chain, the Product Information Standards team is defining that information which is exchanged across the interfaces. The team will adopt standards which sufficiently address information needs, and support standards which are already under development for unmet needs. IPC, for example, recognized the need to supercede currently outdated, but widely used, standards for CAD to CAM exchange, and has introduced the GenCAM standard to fill this gap. Where no standards exist or are planned, the Product Information Standards team will take the initiative to develop a specification.

When a new standard is warranted, it will be developed consistent with the groundwork laid by the NEMI Plug & Play Factory project (see sidebar). Both VFIIP and the Plug & Play Factory project are coordinating any new development efforts with the IPC to ensure a ready pathway for standardization. The first new development effort embarked upon by VFIIP and IPC is in the area of bill of material and quotation information, and is expected to result fairly rapidly in an IPC standard.

Supporting IT Infrastructure Team

The process of sharing information within the supply chain requires an infrastructure to support it. The business process team focuses on why information is exchanged and between which partners; the Product Information Standards team defines what information is exchanged; and this team determines how that data should be exchanged. It will define the virtual IT organization and the information "connectivity" for organization members. The intent is to leverage available technology, such as the World Wide Web, to support the business process and information standards.

Prototype Implementation

The efforts of this group will be the proving ground for the processes, standards and infrastructure developed by the other three teams. Intel and Celestica have pledged resources for an industry demo, and the Georgia Institute of Technology will provide resources for an academic demo.

NEMI Plug & Play Factory Project

NEMI's Plug and Play Factory project has been underway since late 1997 and is scheduled for completion this year. This project focuses on the development of standards necessary to achieve interoperability – i.e., plug and play capability – among hardware components used by North American electronics manufacturers. The goal is to reduce the amount of time and cost that is takes to integrate a new piece of electronics assembly equipment into a shop floor environment and start collecting data and controlling that equipment.

It is estimated that the integration cost of a typical factory information system is up to four times the cost of purchasing that system in the first place. Also, the time that it takes to design and implement a new factory floor system – which can be as long as two years – is much longer than the product technology life cycles of many of today's electronic products. Often, after a long period of analysis and design and implementation, users declare, "It is just what I asked for, but not what I want." The reason for this is that the business model has changed so drastically during the time it took to implement the factory information system that the system is, at best, underutilized and, at worst, never used to support real production.

Activities of the group are broken into three areas:

- Definition of standards for a software framework that will allow interoperability among software and equipment produced by different vendors.
- Development of process-specific machine communication interface standards for surface mount equipment, leveraging the Generic Equipment Model (GEM) specification developed for semiconductor equipment and web-based standards for data transmission.
- Establishment of a test bed manufacturing line at the Georgia Institute of Technology (Atlanta) to prove the concepts developed by the project.

The project has periodically demonstrated the capabilities of the evolving Plug & Play framework. The current iteration of the demo involves data collection over the Internet from a diverse set of electronics manufacturing equipment, all made by different vendors. At the core of the demonstration is a software framework, based on eXtensible Mark-up Language (XML), which provides a common interface among all the hardware components on a PCB manufacturing line.* It allows data to be collected from all the machines on the line and displayed inside a web browser.

The project has successfully demonstrated an order of magnitude reduction in the amount of time and the cost of implementing a new factory information system on an actual electronics manufacturing line, thus achieving its goal of drastically reducing the break-even point for implementing a new factory information system.

* The line used by this project is located at Georgia Tech

Conclusion

VFIIP is hardly alone in identifying and creating standards to ease supply chain integration:

- The RosettaNet consortium has set the goal of creating the "lingua franca for eBusiness" in the areas of product introduction and order management.
- CommerceNet launched the eCo Working Group to define cross-industry electronic commerce standards.
- The Silicon Integration Initiative's (Si^2) Electronic Component Information Exchange (ECIX) project is dedicated to designing standards for creation, exchange and use of

NIST Internet Commerce for Manufacturing

The Internet Commerce for Manufacturing (ICM) project, established in January 1998 as part of NIST's National Advanced Manufacturing Testbed, is working with industry to develop, validate and demonstrate the use of open systems and standards to efficiently share printed circuit assembly data between electronics manufacturers and their supply chain partners. The aim of the ICM project is to create an easily replicable scenario for Internet-based electronic commerce spanning the complex supply chain common in today's electronics industry. The ICM project will implement a prototype supply chain by linking together commercial and prototype software applications through a suite of proposed and actual standards, such as those expected from NEMI's VFIIP initiative. The project is also encouraging the development of web-based pay-per-use services, to enable small and medium sized manufacturers to share in the Internet's potential benefits.

ICM project accomplishments include:

- Implementation of a distributed testbed, linking together commercial applications and prototype software to demonstrate potential supply chain efficiency gains through more efficient use of the Internet and information exchange standards. Software and specifications showcased in the testbed include: the NEMI Plug & Play Factory testbed at Georgia Tech; Agile Software's product change collaboration tools; Automata Design Inc.'s manufacturability analysis software; and IPC's GenCAM standard.
- Development of a web-based Standards Roadmap to help navigate industry through over 700 information technology related standards.
- Release of a Conformance Test Module for the IPC GenCAM standard.
- Procurement of two actual boards via an electronic bid site with web-accessible design information.

* The line used in this case is the Georgia Tech test bed.

electronic component information.

• The National Institute of Standards and Technology's (NIST) Internet Commerce for Manufacturing project is helping to develop, validate and demonstrate standards for business-to-business electronic commerce in the electronics manufacturing supply chain (see left).

The trend toward outsourcing and the related growth in the EMS segment of the electronics industry show no signs of slowing. Increasingly, products are being designed, manufactured and distributed through a complex supply web of OEMs, EMS providers and suppliers. Together, these companies form a virtual enterprise, or e-factory, in which efficient exchange of information and data is key to success. In this environment, development of industry-wide standards for machine interface, communication through the supply chain and exchange of data are critical for continued growth. ■