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CYBERINFRASTRUCTURE ENABLING PERSONALIZED PRODUCTION

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ABSTRACT

The Internet has facilitated the development of e-businesses using web-based services leveraging back-end database systems, inventory systems and payment processing systems. Online retail businesses can be set up in a relatively short period of time. In contrast, set-up of a manufacturing system takes much longer; the system design involves various stages from gaining an understanding of the product and its market to machine selection, layout, control logic, part flow analysis and so on. Cyberinfrastructure has the potential to revolutionize the design and operation of manufacturing systems by creating a collaborative environment distributed across a number of physical locations through web-based virtual communities, thereby simplifying and streamlining the manufacturing system design and integration. This paper describes how current technologies could facilitate the implementation of a cyberinfrastructure for manufacturing. A case study describing a current manufacturing system architecture and how a future one would use cyberinfrastructure is used to describe major gaps that exist and standards that need to be developed.

1 INTRODUCTION

Cyberinfrastructure consists of "computing systems, data storage systems, advanced instruments and data repositories, visualization environments, and people, all linked by high-speed networks to make possible scholarly innovation and discoveries not otherwise possible" [1]. Recognizing that the high-speed internet has enabled the exponential growth of web-based businesses, it is thus interesting to consider how the same ideas could be used to enable the design, integration and the reconfiguration of manufacturing systems. How can the functionality within cyberinfrastructure be used to fundamentally create a paradigm shift in facilitating grass-roots efforts for simplifying the manufacturing process? Can highly collaborative support be provided for streamlining the manufacturing process through distributed virtual communities on the Internet across distinct physical locations?

E-commerce websites – focused on buying and selling products and services – have evolved from closed "pre-web" systems through a reactive web and an interactive web to an integrative web [2]. Cookies, which allow state information to be exchanged between the user's browser and the host website, were the core technology that allowed the transition from a reactive to an integrated web. As a result, a number of services are more commonly offered, which when coupled with the relative low cost of web hosting and software production, leads to a relatively low cost of entry for introducing new e-commerce services. Anecdotal evidence suggests that a new web-based retail site, for example, can be set up in a few days or less.

Application Service Providers (ASPs), a key enabler of e-commerce [3], can be contracted for services such as web-hosting, payroll, billing, scheduling, and accounting services and for outsourcing business tasks to more specialized companies. Using the web, the interfaces to these ASPs are standardized for the users, and it can be straightforward to connect for example the scheduling system to the payroll system. New businesses can purchase the software services – and pay for as much as they use – instead of needing to install, maintain, and operate their own software systems (and associated computer hardware). Amazon can function as an ASP, offering web services such as Amazon EC2 and Amazon S3 with network infrastructure support (e.g. in-memory caching for web applications, web based storage, etc.) and software support (e.g. managing databases, payments, etc.) [4,5].

An e-commerce "mashup" is a type of interactive web application that uses available Application Programming Interfaces (APIs) to extract and combine relevant/ required data from various external online third-party sources (such as web sites) [6]. Mashups facilitate the integration of data between e-commerce merchants that offer APIs, such as Amazon and ebay, to other vendors.

In contrast to e-commerce businesses that focus on buying and selling, manufacturing companies must design and produce tangible hardware products. The initial startup cost and ongoing maintenance overhead for a new production system is significant, especially when compared to the startup and maintenance costs of a new e-commerce venture. When a new business would like to manufacture a product, the breakdown of the product into components that must be built is typically done manually (or by historical experience), and the choice of supplier companies that can make each component is also done by a search (facilitated somewhat by the Internet) plus some personal judgment. If final assembly is not manual, then an assembly system must be designed to produce the product. In recent years, flexible machines and advanced manufacturing system modeling and simulation methods have led to shortened development time; however, it is not uncommon for 12-18 months to be required to set up a new system. Thus, it is interesting to question whether some of the cyberinfrastructure technologies that have lowered the barriers to entry for e-commerce can be scaled or adapted for manufacturing systems.

One of the most exciting opportunities that cyberinfrastructure can potentially offer in the manufacturing domain is the availability of personalization – having the customer participate in designing and making the product. A few examples of this have been realized (see Section 2.2) but significant advancements – most of which involve cyberinfrastructure – are needed to achieve the full potential in this domain.

Large, complex manufacturing industries, such as the automobile industry, often have difficulty offering consumers high levels of product customization or personalization. The difficulty arises partly due to the fact that the products have to keep in accordance with certain standards (e.g. safety standards). Additionally, large manufacturing companies also have limited flexibility for switching between high volume production for the mass market and low volume production personalized for the individual customer.

To address the above issues, cyberinfrastructure technology needs to facilitate the development of the following three features:

1. Distributed enterprises: A distributed enterprise is a network of manufacturing companies that simplifies the supplier identification process for smaller companies. With a distributed enterprise, new companies can take part in sections of the production process, and outsource the remaining jobs to other companies. The new companies can thus enter the industry at an earlier time instead of waiting for the long development cycle associated with establishing a complete manufacturing line for a new product.
2. Product customization/ personalization [7]: Personalization enables consumers to develop their own product identity and encourages innovation among both consumers and developers of personalization software tools.
3. Low-volume production: While still enabling high-volume production, the cyberinfrastructure technology should also aid in facilitating low-volume production for increased product customization and/ or personalization for individual consumers or small organizations.

There is thus a need to evaluate and characterize the changes and/ or enhancements in terms of standards, protocols, architectures, semantics, etc. that are needed for future manufacturing cyberinfrastructure. The structure and the architecture of a manufacturing cyberinfrastructure should encompass the principles of openness, scalability and reconfigurability. Small businesses can be integrated into the distributed network and participate in the operation of the manufacturing cyberinfrastructure to encourage innovation. We limit our focus to discrete part manufacturing systems (characterized by the production of distinct items such as the automobile, semiconductor, toy, shoe manufacturing industries), and not consider continuous processes (characterized by the production of undifferentiated products such as oil, natural gas). In the following sections, we will examine the current technologies that could facilitate the implementation of a cyberinfrastructure for manufacturing. A case study outlining a current manufacturing system architecture and an architecture for a manufacturing industry using cyberinfrastructure is then presented and used to describe major gaps that currently exist.

2 COMPONENTS OF CYBERINFRASTRUCTURE

In order to develop a network that can facilitate design and integration of manufacturing systems, we identified three main areas for the implementation of cyberinfrastructure tools: manufacturing companies and supplier integration, consumer integration with manufacturers and/ or suppliers, and enterprise management and factory floor integration. Figure 1 shows the different levels of integration between consumers, manufacturers and

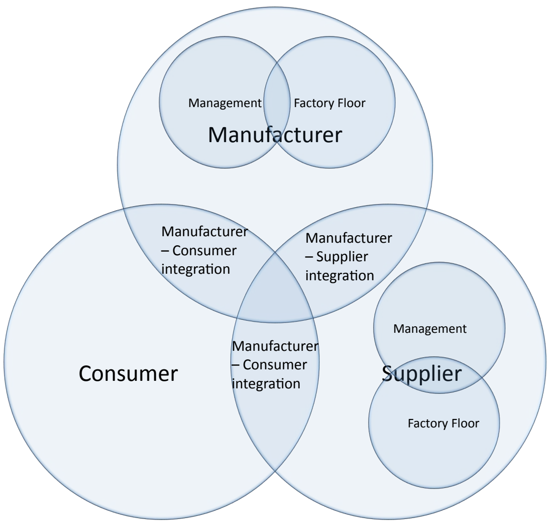

FIGURE 1. ILLUSTRATION OF DIFFERENT LEVELS OF INTEGRATION FOR A MANUFACTURING SECTOR

suppliers. The intersection of the three signifies the triple presence of a company in the integration network as a manufacturer of a product, a supplier for the same or a different product and a consumer purchasing a different product. Figure 2 depicts a possible scenario for the different pieces of cyberinfrastructure (enterprise and manufacturer-supplier integration infrastructure) required for the integration between consumers, manufacturers and suppliers.

Being the area that requires the most innovation, this paper will focus on the integration of manufacturing companies and suppliers and the issues presented. A brief discussion on the current technologies offered for consumer integration and enterprise management and factory floor integration will also be presented in subsequent subsections.

2.1 Manufacturing Companies and Supplier Integration

The long development time for manufacturing systems makes it difficult for smaller companies to enter the manufacturing industry. This issue can be addressed if a distributed network that effectively integrates various manufacturing companies and their suppliers exists.

With regards to how to go about achieving such a distributed network, we consider the RTDI factory for personalized shoe production [8] that offers its suppliers an Intranet Supply Chain Management (SCM) Module that loads order specific CAD/ CAM data for the suppliers, chooses work order to process and gives feedback to the company about the process. Such a concept for integrating a manufacturing company and its supply chain can be extended over a larger domain so that the integration occurs not just between a company and its supply chain; the integration should occur additionally between multiple manufacturing companies and multiple suppliers. For instance, a high-level scheduler that keeps track of various companies and their available resources, status, and so on, can assign an order to a particular company or a set of companies, after an order is processed accordingly. New companies can join the network by integrating their system with the high-level scheduler, which can for instance be organized by a single entity. It is important to note that the primary intent of the organizer would be to provide the technology and services to enable a network of integration (cyberinfrastructure platform) for various other manufacturing and supplier companies. The organizer can therefore be any third party or manufacturer/ supplier company providing the cyberinfrastructure technology.

Since various companies and manufacturers have differing data, data types, format and systems, there is need for common standards, and protocols that facilitate the integration process and represent the architecture of the system. Such standards enabling high level integration between different companies are not common and further research is required to identify their needs and requirements. Networking of the various systems can be achieved via the intranet of the scheduling organizer, over the global internet (essentially permitting unbounded global connectivity), or with any other appropriate sub-network.

Current manufacturing architectures require suppliers or consumers to connect with a particular manufacturer over a proprietary interface. A cyberinfrastructure platform however could enable wide-scale integration across different manufacturers, suppliers and consumers. This raises further issues that need to be addressed. For instance, how much information needs to be exposed to enable collaboration while still preserving the competitive advantages of the individual companies involved? How can a high-level scheduler account for core competency advantages of one supplier over another? Some companies, such as Ponoko [9] and Mfg.com [10], provide access to a network of other companies, manufacturers and suppliers. A request is posted at Ponoko or Mfg.com by a consumer or organization, and interested parties from the network place bids on the request. A suitable supplier can thus be selected in this manner. This type of integration using a bidding system can be utilized to maintain the competitive advantages of individual companies.

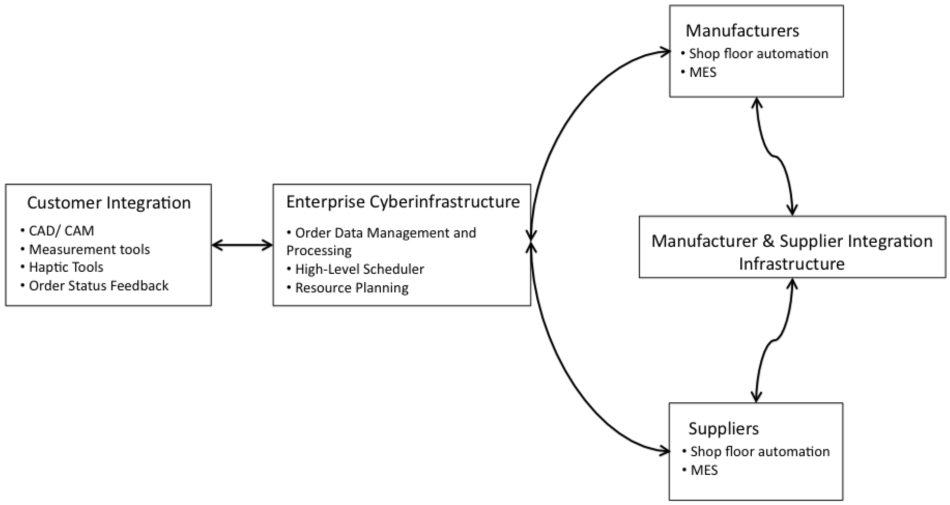

FIGURE 2. CYBERINFRASTRUCTURE FOR INTEGRATION BETWEEN MANUFACTURERS, SUPPLIERS AND CONSUMERS

2.2 Consumer Integration

Continuous developments in customization and personalization allow the consumer to be more involved than with the traditional mass production process. For instance, Dell offers a number of options for consumers to select and reconfigure their products, enabling consumers to virtually assemble their own unique product. On the other hand, do-it-yourself workshops (TechShop, All Hands Active) are becoming increasingly popular, offering consumers access to industrial tools and experts for developing and working on their own projects. The key to consumer integration thus lies in offering one or both of the following:

1. Platform for customization/ personalization of product
2. Platform for driving innovation in a given field/ area

The concept of crowd-sourcing is one that encourages innovation in consumers for a product that may be mass-produced or produced in low volume. Local Motors, a company focusing on small volume production of hobbyist cars, provides the consumer with design and access tools and a platform for designing and showcasing a car body and for collaborating with other consumers and experts. Once the winning design is selected, it is manufactured in low-volume and sent to selected mini-factories where the consumer receives the different car parts as a kit that he/ she can then assemble (note that Local Motors has its own supply chain with the company receiving parts from multiple companies, e.g. the engine and transmission from GM).

A similar concept, DIY Drones provides consumers with tools and kits to develop their own control system for small Unmanned Aerial Vehicles (UAVs) and a git platform (an online version control system) for collaborative software development. Collaboration tools such as those offered by Hubble are essential for an interactive environment that can connect consumers spread out over a wide geographical network and encourage virtual co-design and peer reviews. Conversely, design over a diverse population necessitates the need for a testing and validation scheme that can verify the feasibility and manufacturability of designs developed by consumers. For instance, designs submitted to Local Motors follow a set of a priori design rules and are subject to a feasibility assessment that tests designs against compatibility with chassis mount points, ergonomic space violations and other factors.

2.3 Management And Factory Floor Integration

Currently there exist various architectures and systems that enable flow of information within a factory. Manufacturing Execution Systems (MES) are one such example of a system that manages factory floor operations. [11] offers an architecture consisting of a STEP (an ISO standard, formally titled, Standard for the Exchange of Product model data) compliant knowledge base framework/ schema that exists between the factory floor and the MES system. The framework not only guarantees continuous information flow between the MES and physical devices, but also translates recovery strategies undertaken by MES into XML (Extensible Markup Language) neutral format (Part 28) to be sent to the physical devices. The schema is implemented on an open source software platform using Java based tools and EXPRESS standard data modeling language. Although this architecture facilitates information flow only between the MES and factory floor, it is important in realizing the standards that currently exist for open control system architectures (OSACA, OMEC, etc.). Application of such standards on the factory floor across various manufacturers would greatly facilitate the implementation of a cyberinfrastructure environment.

The Siemens Innovative Production Line (IPL) takes a step further on connecting to the information in the factory floor. The proof of concept production line demonstrates factory floor to management to consumer connectivity and cloud computing. The consumer logs in to place an order that is automatically routed to a manufacturer with production capability. The manufacturers Enterprise Resource Planning (ERP) automatically checks the inventory and orders parts as required. In the actual plant floor, a common platform between stations enables device to device communication and, as assembly progresses, process feedback is provided in the form of status updates, Human Machine Interface (HMI) videos and so on, to both consumers (seeing status updates) and manufacturers (seeing real-time production data).

3 CASE STUDIES

3.1 Cyberinfrastructure Architecture

Consider how a shoe manufacturing industry might be currently set up. Various companies, such as Converse, Nike, Reebok, etc. can offer customized shoes (color, material, size, etc.) to consumers. Figure 3 provides an abstract description of how an order from a customer may be handled. Most of the order processing occurs within the company's internal system. Each consumer order is received through a network such as the Internet and processed by some Order and Data Management Module. A CAM module or some type of a Product Data Management (PDM) module that generates specific CAM data for the order can be implemented and the data stored in a data repository. A Resource Planning Module can then generate production and/ or work orders that it makes available to a factory floor supervision system or to the MES module directly. The MES assigns order to the individual devices on the factory floor. The RTDI factory for personalized shoes [8] employs a similar architecture, using Simple Object Access Protocol (SOAP) messaging and interactive web services for the communication between the MES and the factory floor. Based on the work orders generated by the Resource Planning module, or a module performing a similar function, job-list can be compiled for the industry supply chain that can be sent either manually or automatically to the company suppliers. Indeed, it is possible to have various suppliers contribute through the different stages of the manufacturing and assembly process. Once the order is completed, it is handled by the logistics department and shipped back to the customer.

Figure 4 depicts an example of how cyberinfrastructure capabilities may be employed to develop a distributed manufacturing environment. A high-level Enterprise Cyberinfrastructure (ECI) layer exists between the consumer and the manufacturer and/ or supplier companies. The layer may be handled by a single organizational entity offering communication, data storage, processing and networking between companies, or can be a combination of multiple modules over Internet carrying out the required functionality. Although the layer is depicted as being centralized, it is noteworthy to recognize that to achieve a true distributed and integrated network, a similar layer can exist at many levels, including between individual manufacturer and supplier companies. The Supply Chain Module (SCM) utilized by the RTID factory offers suppliers a convenient interface over Intranet to consult their work order. Since the architecture for CAD/ CAM design process is well- established and consists of standards such as CORE, GKS, CGM [12], it may be possible for the ECI and/ or the SCM layer to provide the option for companies to download the CAD/ CAM specific data.

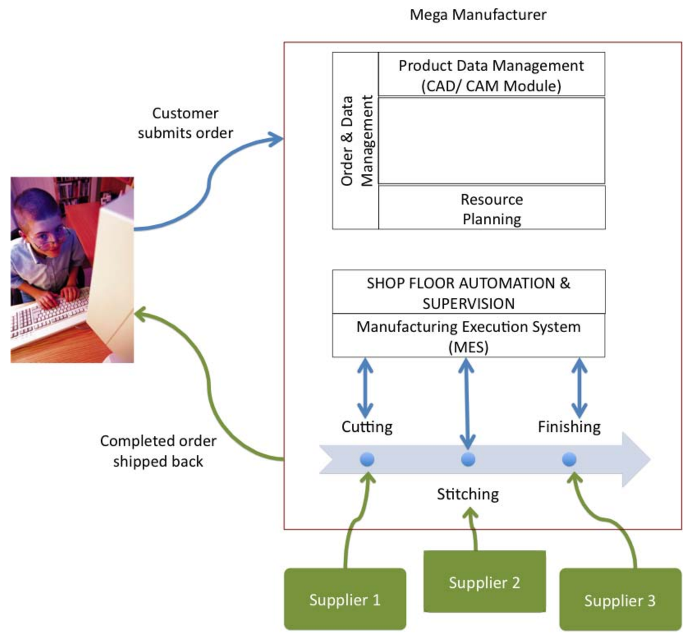

FIGURE 3. AN EXAMPLE OF A MORE RECENT MANUFACTURING ARCHITECTURE

From the processed order data obtained from the customer, a high level Resource Planner can perform company scheduling, assigning each company and/ or supplier with work orders based on available resources. The integration of smaller companies and other independent supplier is thus facilitated. If multiple companies are involved in a manufacturing process, a Logistics Module, implemented either within the ECI module with inputs from the various companies or between the companies themselves, can keeping track of order status and locations and provide status feedback to the consumer. Finally, the use of scan tools that scan the customers feet for a "perfect-fit" shoe can enhance the consumer experience and provide a highly personalized environment.

For different manufacturing industries, a similar infrastructure can be employed. Depending on the product, the CI tools that the customer has access to can vary. [13] presents an innovative system aimed at designers for modeling industrial products based on haptic technology consisting of a CAD system

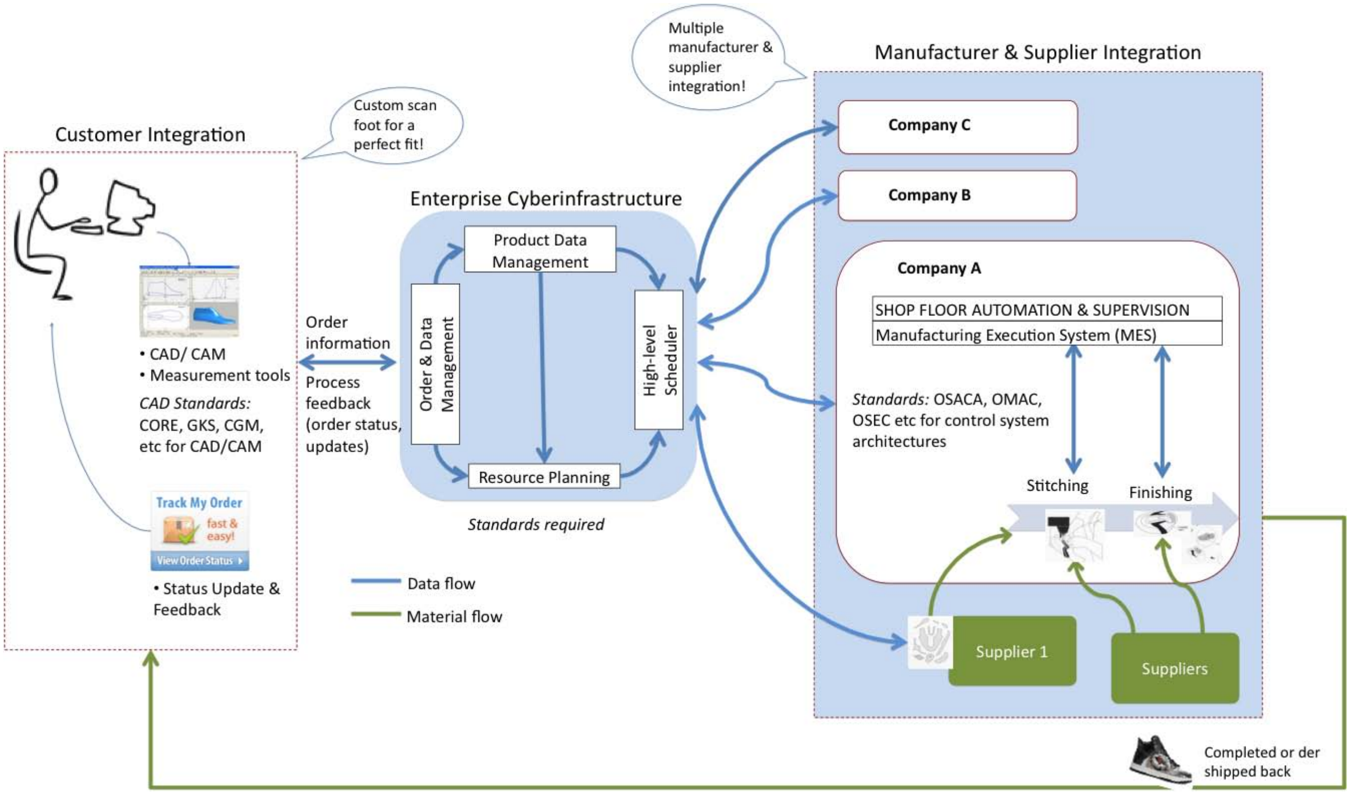

FIGURE 4. A POSSIBLE ARCHITECTURE FOR CYBERINFRASTRUCTURE IN MANUFACTURING

coupled with designer-oriented interaction tools. [14] presents a comprehensive discussion of various efforts and techniques for offering virtual prototyping for the garment industry, including MIRALab's Virtual Try On (VTO) application being developed to offer the consumer information about garment fit and behavior based on body sizing, motion retargeting and garment simulation technologies. The use of such tools to improve consumer experience enhance the CI architecture and encourage innovation among both consumers and developers. As outlined in the previous section, current technologies and various research efforts also exist for integrating the factory floor to the management for various manufacturing industries. Additionally, to some level, manufacturing companies already offer software support for integration with their suppliers. To address the issue of a distributed service organization, on an abstract level, a concept, similar to that outlined in Fig. 1, can still be applied for integration between various manufacturing companies and suppliers, regardless of the kind of manufacturing industry.

3.2 Cyberinfrastructure for Crowd-sourced Designs

The past few years have seen a number of small companies try to embrace recent technological advances in an attempt to make portions of the manufacturing process more distributed. Companies such as the Ann Arbor T-shirt company and DIY Drones offer consumers platforms and/ or various tools with the intent of crowd-sourcing the design of new products.

Founded in 2007, Local Motors, Inc., an open-source automobile company, as it is called, is dedicated to co-creating vehicles with a community consisting of consumers, hobbyists, designers and engineers. A visit to the factory site was helpful for understanding and providing a perspective on how cyberinfrastructure can be utilized to help achieve the goals of the company, which in the long term is to be able to provide the consumer with the complete design and build tools such that they can aid in every step of the car design process, assemble and build the car using kits, tools and expertise provided at the micro-factory locations and finally, customize the car to their tastes. The following two subsections outline the efforts currently invested by Local Motors in order to distribute the manufacturing process further by providing additional tools and/ or platforms for : 1) enhancing consumer collaboration during the design process and, 2) simplifying the supplier identification process for component selection by trying to identify a network of relevant suppliers to choose from.

3.2.1 Design The RallyFighter, the only current car variant that Local Motors builds, was based on a winning design selected purely on aesthetic quality. The few constraints that were provided by Local Motors were limited to constraints for certain chassis mount points and ergonomics (such as carrier capacity and so on) and did not take into account the engineering or manufacturing feasibility. The selected design was modified keeping in mind the engineering constraints and the features desired by the community. Current efforts by the company focus on the implementation of an online CAD/ design software that can be downloaded for use by consumers and used as a standard for collaboration of the design. However, the software, in addition to providing a standardized platform, was also required to be flexible so as not to limit the portion of the community using different design software. Future endeavors might include Local Motors offering software enabling the community to perform or participate in different forms of engineering and manufacturing analysis (finite-element analysis, etc.), such that the final product assembled at Local Motors is closer to the final designs developed by the community. One of the chief concerns addressed here is the extent to which the community should be involved in the design of the automobiles, such that the company can maintain the rights to the finished product.

3.2.2 Component Selection The car chassis is one of the few components assembled and welded by Local Motors. Other components, such as the engine, transmission, etc. are outsourced, based on consumer requirements. Currently, Local Motors to identifies a list of suppliers who can provide the components in the required amount and to satisfy the consumer-desired features. For instance, in the case of the RallyFighter, a GM crate engine and transmission are used. However, current methods of supplier identification are based on research and experience. There is thus some effort invested by Local Motors in trying to find and gain access to a network of reliable supplier companies which would aid in simplifying the supplier identification process. However, such an open, distributed network for the automotive industry and related manufacturers is currently not well established.

4 CONCLUSION AND FUTURE WORK

The main contribution of this paper lies in trying to define the problem and realize key challenges for the development and use of cyberinfrastructure technology in manufacturing industries. In this paper, we provide a review of current technology and tools that exist and can be utilized for the development of cyberinfrastructure for manufacturing systems. The hierarchical service organization that currently exists for manufacturing industries, coupled with the long development periods attributed to a manufacturing company ramp up, render it difficult for smaller companies to enter the industry. We saw examples of how integration of various companies and external sources are performed for e-commerce through the use of ASPs, and other software technologies. We believe that similar application of cyberinfrastructure to create a more distributed network of manufacturers and suppliers can help reduce the ramp up time for smaller companies entering the industry by distributing the manufacturing process across different parts of the distributed network.

However, the multitude of companies using numerous different data formats, machinery, hardware and operating system specifications indicates the need for globalized standards to facilitate the production of a product through a synergy of manufacturing companies and suppliers. To some extent, such standards exist for certain areas, such as control architectures and CAD/ CAM. However, protocols and networks that can integrate companies and consumers at a higher level need to be developed. Cyberinfrastructure tools will enable a distributed environment with networks connecting various companies, enabling the industry to respond efficiently to high and low volume product demands. As shown by the case studies, some cyberinfrastructure tools will also enhance the consumer experience by enabling high levels of customization and/ or personalization. However, further research needs to be performed to understand what kind of manufactured products (e.g. mass produced, mass customized, personalized, etc.) would most benefit from the adoption of a new manufacturing cyberinfrastructure. Future work should entail understanding the trade-offs, if any, between the requirements and cost of implementing the cyberinfratsructure platform and the benefits from scale and interoperability between manufacturing companies.

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