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Review

e-Manufacturing: Characteristics, applications and potentials

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Abstract

In this paper, an engineering oriented approach is proposed towards e-manufacturing and its applications. The characteristics and potential of e-manufacturing are presented with a number of application examples developed by the authors' research group. The advances in e-manufacturing and applications are also highlighted and critically reviewed. The paper concludes with a further discussion on the promises and impact of e-manufacturing technology and philosophy on modern manufacturing industry and the practices.

Keywords: e-manufacturing; e-design; Global manufacturing; Agile manufacturing; Digital manufacturing

1. Introduction

In the last two decades or so, manufacturing industry has experienced some notable changes, e.g. from mass production through flexible and lean manufacturing towards agile manufacturing and e-manufacturing philosophy, as shown in Fig. 1 [1–3]. The changes are directly driven by the requirements for a product's price, quality, delivery performance, customer choice, etc., which may result from the factors of unexpected changes of competitive market environment, globalisation of market, a variety of customers' demands, customer-designed products, and shortened product life cycle. These factors have great impacts on all the manufacturing-related activities such as order, design, planning, manufacturing, workshop floor control, assembly, delivery, maintenance, services, and marketing.

Manufacturers have to work hard to achieve not only high quality, productivity and reduced cost, but also the ability to react quickly, responsively and effectively to the market, which is becoming more international, dynamic and customer-driven. For instance, many European manufacturers design their products in Europe and manufacture them in Far East Asia, and then sell the products at high volume in North America or other continents, as do the American manufacturers. Such global-wide manufacturing phenomena are getting to be more common in manufacturing industry in the late 1990s. Maintaining design and manufacturing agility and working on the extended product development chain are the key for these manufacturing companies to be successful and cope with such phenomena.

To become agile, manufacturers have to distribute intelligence and decision-making authority as close to the points of delivery, sale and even after-sale service as possible. To improve their ability to respond, they have to integrate the design and production information with their business partners. To stay in business, they have to be prepared to change the very definition of their core business if business goals and market conditions dictate. e-Manufacturing technology is a promising enabled technology to achieve such agility in the changing manufacturing business.

The advance of modern manufacturing technology has been characterized by two aspects: automation and high precision as achieved. e-Manufacturing enables the higher level of automation of manufacturing business information rather than physical one as used to be, and therefore improves the information flow and work flow throughout

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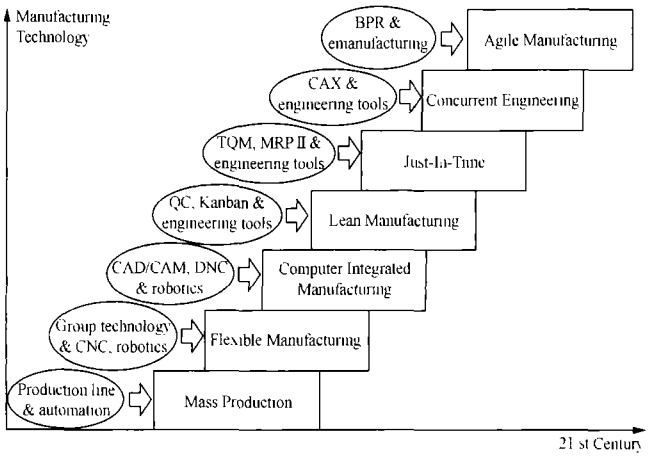

Fig. 1. Development in manufacturing technology.

the organization and thus the manufacturing efficiency and effectiveness. Furthermore, e-manufacturing is about more than Internet-based technology. It involves every aspects of how a manufacturing organization does business including

- Design of manufacturing and business strategy
- Sales and marketing
- e-Procurement
- Shop-floor operations
- Enterprise application integration
- Supply chain collaboration
- Transactional e-business – providing real-time visibility
- Collaborative engineering

e-Manufacturing is not an event; it is the result of an evolving process that manufacturing business will continue to refine as technology capabilities expand and business conditions change.

Many companies are currently developing comprehensive e-manufacturing suites, platforms and systems, especially for enterprise application integration purposes [4]. For instance, Sun Microsystems has developed SunConnect, an open standard framework, which enables all kinds of manufacturing organizations to integrate the power of their legacy systems and make their data, application and networking resources available across their entire enterprise. Many manufacturing SMEs are using computer-based tools combining Web-based program for supporting their manufacturing and business operations [5]. e-Manufacturing is an essential and inevitable technology for the future manufacturing organizations, working along the extended supply chains in particular.

2. Characteristics of e-manufacturing

Internet-based e-manufacturing covers the range of online manufacturing activities for products and services, including product design, production control and conditions monitoring, supply chain management, maintenance and sale services through the Internet. The characteristics of e-manufacturing emphases the new philosophy through which manufacturing will be operated in integration with Internet technology. e-Manufacturing philosophy naturally results from that the way people work is being changed by the Internet, for instance [6].

Digitisation: Any manufacturing related information that can be digitised could be stored and accessed through Internet within or outside a manufacturing company.

Globalisation: The global nature of Internet provides manufacturing companies with the infrastructure to support their engineers, partners and customers with access to information, regardless of where they are physically.

Mobility: Engineers who need to travel to support customers are no longer constrained by the inability to access information that resides within the company. Internet enables accessing information from any place and at any time, which can improve the agility and responsiveness of a company to customer needs.

Collaborative work: Internet technology supports data sharing and work collaboration. Companies can create joint development teams, where members of the team can reside in different geographic areas. Project information and interactive conversations can be hosted on the Internet. A variety of collaboration tools such as newsgroups, chat groups, bulletin boards, integrated design and manufacturing tools, can be used, so the members of the team can effectively and efficiently communicate and share ideas, information and data.

Immediacy: By accessing a website, a supplier's extranet, or the company's intranet, the latest manufacturing related information can be accessed instantly. Engineers can have real-time access to information whenever they need.

e-Manufacturing is starting to change the nature and characteristics of manufacturing operations as highlighted in Fig. 2, albeit the changes are varied from sectors to sectors [7–9]. In the case of some manufacturing organizations, e.g. computer manufacturers like Dell Computers, e-manufacturing philosophy (make-to-order, etc.) has allowed radical changes in the manner, in which design, manufacturing, sales and services are executed.

3. e-Manufacturing practices, promises and future possibilities

e-Manufacturing has been practiced by more and more manufacturing companies including small and medium sized enterprises (SMEs). Table 1 lists a number of e-man-

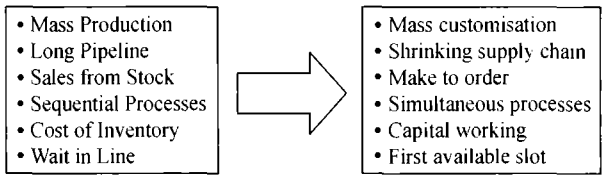

Fig. 2. Transformation driven by e-manufacturing.

Table 1
e-Manufacturing case studies

Company	Solutions	Industrial sector	Cost £ 000's
Alex engineering	Having installed better CNC machines and other tooling, to implement a 'Job Shop' managing system with an emphasis on capacity planning and job costing	Subcontract engineering	20
Goodridge	To install a scaleable, multi-language, multi-currency integrated ERP system, handling everything from order entry to manufacturing, with five new assembly shops	Automotive SME	400
Edinburgh crystal	To build an automated on-line web store, linked to Internet banking, to the firm's ERP systems and to the contract shipping company's third party logistics system	Glass making	ERP: 43 Web: 12
Dean foods	To implement a fully automated preventative plant equipment maintenance system, and to integrate that with Internet-based spare parts procurement	Dairy	8
Giroflex	To implement a company-wide ERP system using a rules-based costing, configuration and promising system, as well as APS, to drive everything from sales order processing	Office furniture	500
Moss plastics	To implement an ERP system and integrate shop floor data collection, advanced planning and scheduling, and ultimately e-commerce and customer relationship management	Plastic components	ERP:1500 upgrades 500
Thorlux lighting	To improve design for manufacturing and move to cell manufacturing supported by an ERP system covering SOP, manufacturing and warehousing with a unified front end product configurator	Lighting systems	1000
Perkins engines	An intelligent, web browser-based e-catalogue called SPI, which incorporates all spares, servicing and maintenance information. Using a Web-to-DVD download approach, customers and distributors are kept fully updated with all engine-related modifications	Power generation	N/A
Xtrac engineering	To upgrade existing CAD/CAM software so that CAD data can be imported directly into the programming software via network	Automotive	Less than 1
Hothouse centre	To implement virtual reality (VR) software, including product visualisation tools, 3D modelling software and force-feedback devices, to allow potters to interact with screen images	Ceramics	25

ufacturing case studies, which summarizes the manufacturers' own views about what they have achieved, how and why they did it and its value and importance to them [10]. For all these applications, there are 18 key elements which should be part of the application approach for any fully fledged e-manufacturing solution including

- Electronic technical and commercial systems
- Systems and applications for sharing information
- Protected and security systems
- Infrastructure for sharing information
- Customer and supplier communications
- Information to agreed standards
- Managed, shared information and knowledge
- Electronic 'through life' information
- Information to support management decisions
- Clear total process model and strategy
- Documented process supported by procedures
- Electronically supported processes
- Secure processes
- Concurrent engineering
- An e-business vision
- Effective training
- Effective team working
- Supportive organization

At research front, the UK founding councils, European Union and the National Science Foundation of the USA are currently funding heavily on e-technologies and e-applications through various large-scale research programs such as, e-Science, e-Society and EU 5th, 6th Framework IST (Information Society Technology)

programs [11–14]. Social, cultural and political processes will also help to shape innovations in products, services and industries, including the structure and operations of the manufacturing industry. For a manufacturing company, either a multi-national or SMEs, e-manufacturing technology and underlying philosophy are providing the tremendous opportunities, promises and future to achieve unbeatable competitiveness and sustained growth in the market place.

4. e-Manufacturing research and development

There are a great number of e-manufacturing development and application cases, although they are more driven by applications in various manufacturing sectors. The following two sections intend to use the authors' own work as examples to highlight the research and development in e-manufacturing rather to exclude many excellent work carried out by others:

(1) An Internet-based e-manufacturing library has been developed at Brunel University. The library includes the following modules [15]:

- InterNet-based rolling bearing design support system (Net-Bearing)
- Java-based machining simulator for turning operation (J-SimuTurn)
- Java-based machining simulator for milling operation (J-SimuMill)
- InterNet-based virtual manufacturing enterprise (Net-Enterprise)
- Java-based tolerancing for bearing-shaft assembly (J-Tolerancing)
- 3D assembly application – Peatey's coatings (Peateys)
- Generic tooling selection application based on case-based reasoning (WidiaTurning)

For instance, the first module is an Internet-based design support system for rolling elements bearings. Fig. 3 shows the front page of the system. The system includes seven functional modules including electronic catalogue, intelligent selection, mounting details, sealing devices, lubrication, manufacturing database and design module [16]. The system aims at providing comprehensive, responsive and rapid bearing selection and design support for the large engineering community by taking advantage of the speed, ease of access and low cost of Internet-based technology.

The system is developed using HTML, JavaScript, Java and client/server architecture combined with AI techniques. All modules in the system are hyperlinked in an organic and associative way. A system user can enter any module by clicking the module icon on the system front page. The modular structure allows the system to be easily modified, updated, and user-friendly.

The last module is a web-based CBR (case-based reasoning) system for tooling selection [17]. The main idea is that given some entry parameters such as a turning operation and a material type, the system will generate a list of possible configurations (or cases) to be used, the most appropriate case adopted and refined by the user can then be added onto the database. Fig. 4 shows a 3D interactive simulation for testing the tooling inserts selected for specific turning operations, which is a powerful part of the module.

The details of the e-manufacturing library can be accessed, and further explored at its website [15].

(2) A further project [18] researched on the potential uses of rapid manufacturing (RM) technologies for e-manufacturing purposes is undertaken by the authors in order to improve, innovate or expand conventional manufacturing approaches based on combining the techniques of RM, e-manufacturing and mass customization.

Rapid manufacturing [19] is effectively a logical extension of the types of additive technologies used in current generation Rapid Prototyping (RP) machines, which enable parts or products to be manufactured by the accurate addition of material to build the part layer by layer.

One outcome of this project was the development and testing of the novel 'Devolved Manufacturing' (DM) concept. In this concept, a network of RM providers could be

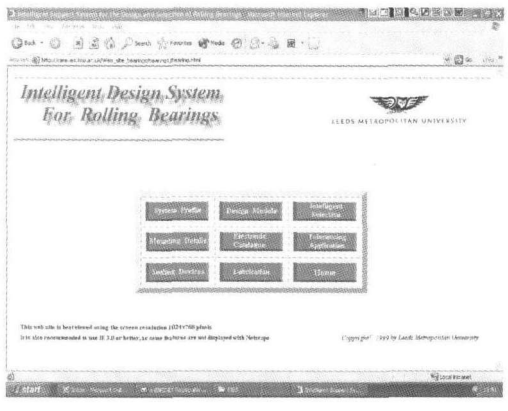

Fig. 3. Front page of an Internet-based bearings design support system.

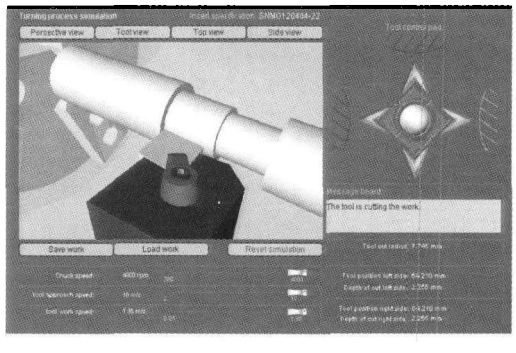

Fig. 4. 3D interactive simulation for turning operations (within the module).

used to allow customers to design parts or products, and then have them manufactured at their nearest manufacturing outlet – which could be on the local industrial estate or even in the high street. This process allows the speedy creation of items on an as-needed basis, and dispenses with lengthy lead times caused by logistic and delivery issues.

Fig. 5 shows a sample of screens from one of the scenarios used to prove the technical viability of the concept. The CAL system was created to allow the modification of the internal spline pattern of a standard CAD model for the centre hub assembly on the friction plate of a race/rally clutch. The internal spline pattern is the 'interface' between the clutch and the gearbox input shaft, and determines whether it can be used for a particular gearbox.

The CAL system was designed to allow the input of a few standard spline parameters to drive the modification of a standard CAD model, which is then rapidly manufactured at nearest local facility. The advantages of this method of manufacture include the ability to manufacture on demand (without costly stockholding), creation of complex CAD model without the need for expensive CAD software and expertise, and the ability to offer a wider range of clutch 'solutions'. This customised service would be relatively expensive compared to the standard mass-manufactured parts, but could be offered as a high value-added solution in cases, where there is no realistic alternative for the customer.

Fig. 6 shows sample screens from a second example wydiwyg.co.uk (what you design is what you get), which is a web-based virtual organization designed to allow customers to download a simple free mini-CAD programme – with which they can design their own products (offline) without the expense and complication of a full-blown CAD programme.

Once the customers are satisfied with their design, the CAD file is uploaded to the WYSIWYG site, where the customer chooses a manufacturing outlet in their locale

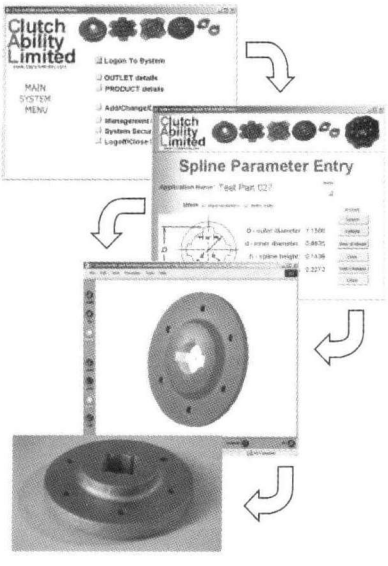

Fig. 5. Sample screens from the CAL system.

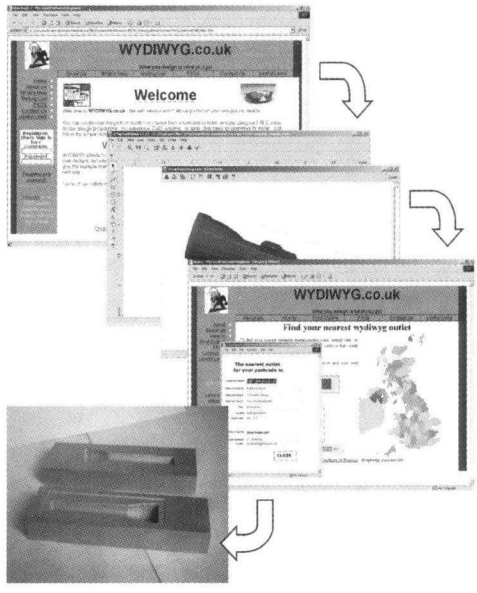

Fig. 6. Samples from the wydiwyg.co.uk site.

for the product to be manufactured. After the important step of paying for it (!), the item can then be collected in the next day or two or at their convenience.

These types of manufacturing ventures require the development of a network of rapid manufacturing outlets which cover the country. As yet such a network does not exist, but recent developments in the usability, capability and speed of current generation of rapid prototyping machines and the materials available for manufacturing using these technologies suggest that this may well become reality in the near future [20–21]. The use of franchise business models for example could enable the rapid creation of RM facilities around the globe and one authority [22] has already suggested that high street photocopy outlets may well be ideally placed for entry into this market.

5. Concluding remarks

e-Manufacturing is opening up opportunities for data intensive activities such as on-line monitoring and diagnostics of machine tools conditions and knowledge intensive processes including new product development, complex systems modelling and simulation, and real-time decision-making supports and complex problems solving. Extended networks of engineers, working together using common product data models across time zones are technically feasible, and many larger manufacturers are embracing this opportunity for reducing product lead time and increasing the exploitation and sharing of design and manufacturing expertise, as well as support for engineering innovation and complex problems solving. With the advance of web-based and grid-computing technologies, there have been a number of e-manufacturing applications well applied to various industrial sectors. However, it is essential and much needed to investigate the methodology and system-

atic approach to the applications and systems implementation. The e-manufacturing is becoming increasingly important in the climate of global manufacturing as a philosophy for working on extended supply chains, outsourcing, devolved manufacturing onto low-cost regions and countries, and maintaining the competitiveness and technological innovation.

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