Future manufacturing systems—Towards the extended enterprise

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Abstract

Manufacturing research has been focused on point solutions and technology-driven solutions. These have not delivered the step changes in performance needed, nor have they been adopted by wide sections of industry so the total business benefit resulting has been modest. The authors propose that manufacturing research must now place greater emphasis on total manufacturing business systems development. Coupled with the integration and communication technologies now becoming available this is the best way to enable manufacturers to realise the competitive gain demanded by the market place.

The primary pressures to which manufacturing will be subject are detailed. These are encapsulated in the concept of customer-driven manufacturing business systems. In these systems the customer increasingly becomes an integrated part of both the business systems and the engineering systems of the enterprise. Key product and process technological advances, environmental, and market place developments are described. Probably most significant are the changes in the value chain now emerging which transform manufacturing business systems and overturn both conventional manufacturing strategy and existing manufacturing metrics. The institutionalisation of the Extended Enterprise is one of the most tangible and has far reaching outcomes. This will involve major structural changes in business organisation. The basis of partnership within the Extended Enterprise is not yet well understood but alternative operations models are likely to be industry and market sector specific. Concurrent Engineering is becoming accepted but understanding of best practice on how, when and in what order to implement it is needed. The extension of tools to embrace environmental issues could offer significant benefit to small and medium sized enterprises. The appraisal of manufacturing business options must be developed to match the changes in the business operations environment described above.

Keywords: Extended Enterprise; Manufacturing system research

1. Introduction

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This paper is an outcome of a study conducted to define technical areas for which research ac-
tion at CEC level is most appropriate and to prepare a proposal for a global RTD strategy. The study was commissioned by DGXII of the Commission of the European Communities.

The study focuses exclusively on the system of manufacturing. Thus there is no attempt to consider the potential for improving the performance of individual activities or operations in manufacturing. Rather the study concentrates on a holistic view of the manufacturing system and defines approaches which seek to optimise system performance.

In Section 2 we consider the context in which manufacturing systems studies now take place. The pressures on the manufacturing enterprise are tremendous and fall within three broad categories: manufacturing takes place in a global economy where local markets are subject to global standards; manufacturing systems are required to develop and operate environmentally friendly products and processes; the business and organisational structures within which manufacturing operates are under increasing stress.

In Section 3 we consider in more detail the pressures identified in Section 2 and argue that they lead to greater co-operation across the total value chain—the sub-supplier, supplier, assembler, customer chain—indeed to close co-operation between enterprises on the value chain to satisfy customer needs. We argue that manufacturing systems must now be considered in the context of the value chain. If the challenge of CIM in the past was to realise integration within the factory, the challenge to manufacturing in the future is to facilitate inter-enterprise networking across the value chain. We discuss in detail five important issues which arise as manufacturing companies seek to achieve inter-enterprise networking.

2. A context for manufacturing systems

Skinner [1] reported that “A company's manufacturing function is either a competitive weapon or a corporate millstone. It is seldom neutral ... few top managers are aware that what appear to be routine manufacturing decisions frequently come to limit the corporation's strategic options”. Later Skinner [2] acknowledged the situation had changed: “After years of neglect, top management's attention has been captured ... the action in manufacturing has been extraordinary in these last five years”.

The emphasis on the manufacturing function led to an improvement in manufacturing performance. The “Manufacturing Futures Survey”, conducted by Boston University, INSEAD in France and Waseda University in Japan [3] identified significant improvements in manufacturing performance over a range of indicators. Their survey of five hundred companies in the US, Japan and Europe pointed to improvement in inventory turnover, level of product variety, delivery reliability, customer service, overall quality, the speed of introduction of new products, manufacturing lead time and manufacturing cost. It is worth noting the performance indicators used to measure improvements—no longer is manufacturing cost the only important criterion.

The performance indicators identified and used in the Manufacturing Futures Survey are indicative of the pressures placed on manufacturing by today's business environment and discerning customers. Further these pressures are felt by companies across the developed world. The same study reports that “statistical analyses show few differences in perceived competitiveness across the regions (Japan, US, Europe) on such critical variables as conformance quality, product reliability, cost and delivery dependability”. The performance indicators subject to the most rapid change were: inventory turnover, quality and customer service, time-based competition and flexibility. These might well be considered to be performance measures which reflect most closely the emergence of “lean production”. The report did however identify big differences in future manufacturing priorities in the next five years. The Japanese foresee the “constantly launching new product period”, which is not recognised by the European or USA data.

In fact these performance measures reflect some of the pressures now placed on the manufacturing enterprise and the goals which the en-

The pressures emerge from the following factors:

(1) Manufacturing now takes place in a global economy.
- How and where raw materials are transformed is a strategic decision. The decision is complicated in terms of what to make and where to make or buy it, in what is becoming a single global economy. An aspect of the development of the global economy is the formation of strategic alliances between companies. Frequently these alliances include co-operative production agreements.
- Customers are very discerning in terms of price, quality, cost, delivery and the availability of customised features.
- Markets are time-based competitive. Increasingly, for many products, time to market is a critical issue in terms of gaining market share and achieving profitability.
- We are moving towards customer-driven manufacturing. The products of the future will be required in a wider array of models and variations. The expectations of customers in terms of customised features means that the customer is engaged more closely with the manufacturing plant. In a make-to-order and ultimately an engineer-to-order environment, the manufacturing plant must be able to deal with orders for customised products from customers.
- Trade barriers are gradually coming down, further opening up global markets. The recent opening up of Eastern European markets is important, not only in terms of future markets but also in terms of the needs of those markets. It is likely that the needs of customers in Eastern Europe will be somewhat different in kind to those of the advanced Western European economies. Thus, whereas customisation and quality may be important issues in Western Europe, volume and price may be far more important in Eastern Europe.

(2) Manufacturing systems are required to develop environmentally benign products and processes.
- Public opinion is increasingly aware of the environmental impact of manufacturing processes and indeed the products of manufacturing.
- Legislation will increasingly constrain product and process design in terms of energy utilisation, the use of recyclable materials, the safe disposal and indeed the reuse of products at the end of their life.
- Increasingly product liability extends up and down the supply chain.

(3) Business and organisational structures are under increasing stress.
- The business focus on core activities increases reliance on subcontractors and suppliers. In the past, management saw vertical integration as the most effective way to manage the complete production process. Today management see advantages in subcontracting non-core business activities to outside suppliers—the approach is frequently called outsourcing—and maintaining control over supplier networks. Supply chain management is therefore an important technique.
- The availability of information technology and telecommunications products supports distributed working. Also the use of EDI (Electronic Data Interchange) technology supports the networking of component suppliers, assemblers and customers.
- Many of today's manufacturing organisations are designed on vertical and hierarchical principles. The move toward hierarchical structures is and will continue to displace middle managers. Organisational structures are being flattened. The number of supervisory personnel is reduced. Today's supervisors work in a consultative rather than an authoritative mode. They facilitate rather than control work. In the old mode of operation managers managed and operators worked. Tasks were divided between manual unskilled tasks and planning tasks executed by specialists. Today tasks are designed to allow teams to plan and execute their own work.
- There seems to be some difficulty in attracting sufficient numbers of intelligent young people into manufacturing. For many young people, manufacturing engineering is not seen as a rewarding career path.
The working population is becoming older and more experienced, and may have greater difficulty adapting to change. It will increasingly comprise female, part-time, home-based and contract labour.

We will consider these issues in more detail in Section 3. Furthermore, we will argue that these pressures result in a new form of manufacturing system which works closely with networks of suppliers on the one hand and customers on the other hand to develop customised products in very short lead times.

3. Towards the extended enterprise

We have identified in the previous section three clusters of pressures, namely globalization, environmentally benign production and business and organisational structures. These pressures will be discussed in more detail below in Section 3.1. These pressures combine to force individual enterprises to work together across the value chain in order to meet customer needs. We term this networking of enterprises, inter-enterprise networking. Our contention is that inter-enterprise networking represents the future shape of manufacturing systems. We will explore inter-enterprise networking in detail in Section 3.2 following. Five important issues of inter-enterprise networking are investigated in Section 3.3. Finally in Section 3.4, we will offer some ideas on how companies might evolve towards the inter-enterprise networking model. We will argue that approaches such as JIT, WCM, Lean Production, Benchmarking and Business Process Redesign are part of this process of evolution.

3.1. Pressures in the manufacturing environment

We will now discuss in detail the three clusters of pressures now bearing down on manufacturing systems, namely globalization, the need to develop environmentally benign products and products and the new business and organisational structures now emerging.

Globalization is a key word in manufacturing for the next decade. International competition is rapidly replacing national competition due to open markets, with increased size, accessibility and homogeneity. The reduction of trade barriers, the harmonisation of laws, and the improvement of transportation have paved the way for competitors everywhere in the community. Consequently, local competition operates in the context of global standards.

Technological developments in manufacturing technology contribute to globalization also. Miniaturisation is such a development. Clearly, miniaturisation leads to a lower proportion of transportation costs in the value chain. Therefore, manufacturing for remote markets becomes feasible. Further, competitive prices for miniaturised products imply large investments and high volumes. This development too leads to globalization. At the same time, large investments and high volumes lead to more subcontracting and outsourcing.

In the current situation near-state-of-the-art technology is increasingly available anywhere in the world. For many manufacturing products, direct labour costs are less than 10% of costs, so products can be manufactured anywhere and sold everywhere. The basis of competition in global markets is excellence in core competence.

In the case of increased competition due to globalization, a well known reaction is to search for a market niche in the enlarged market. Two other responses to severe competition are also worthy of note: decreasing product life cycles and increasing added value by improved service.

The decrease of product life cycles is a well known phenomenon. It is a consequence of the fact that high prices are frequently only possible in the introductory phases of the product life cycle. This is because global competitors have the power to react quickly after the introduction of an innovative product to the market. These reactions enforce shorter product life cycles. Furthermore, today's rapid technological developments make these shorter product life cycles feasible.

Increasing added value by improving service is a frequent response to severe competition. As a first step companies will often increase the variety within a product family, in order to improve customer satisfaction. A second step in the same
direction is to add value by providing better information, repair, training and other services around the product. For standard commodity items, this is combined with direct marketing and shorter distribution channels.

For customisable products, a third step towards improved service lies in customer-order-driven manufacturing and distribution. Ultimately, the sales office may be transformed into a multimedia telecommunications service: the customer is enabled to drive manufacturing and physical distribution operations as a "prosumer" (proactive consumer) to create a "proservice" (product plus service) for his/her own needs. In a sense this notion of future manufacturing extends the traditional meaning of the manufacturing system considerably; it re-integrates sales with production, but decouples distribution from sales (see Fig. 1a and b).

For example many multinational companies in the electronics sector used to have their national organisations as the primary structuring principle until the late eighties. This means, for example, that the sales force of these companies was organised per country, and that physical distribution was organised around the main storage point in the country. In recent years, the primary structuring principle has become the business unit. This means that the sales price is organised primarily by business unit, and that the co-ordination of sales effort per country has been weakened. Physical distribution per business unit differs considerably from physical distribution per country. When physical distribution is organised per business unit, the idea of a main storage point per country for all products of a company becomes obsolete. Business units will organise physical distribution in a way which optimises the performance of the business unit. This leads normally to shorter distribution chains, less stocking.
points, higher frequency of transportation and a closer connection from factory to customers.

The re-integration of sales with production can be seen very clearly in the production of personal products, e.g., limb prostheses. For example Hasegawa [4] has speculated on the impact of what he terms “next generation CIM” on the production and sales of shoes. His ideas are outlined in Fig. 2. The re-integration of sales with production and the emergence of customer-order-driven manufacturing contrasts strongly with the make-to-stock approach of “conventional CIM”. The difference is that the voice of customers is a real-time part of the manufacturing system. Conventional systems restrict customer input to exterior boundaries of the manufacturing system—i.e. pre design and post distribution.

Environmentally benign production is another key word in this study. Society is putting pressure on manufacturers, in order to create production systems which are neutral with respect to the environment. This pressure acts through government regulations and customer requests. It may take the form of legal regulations, economic and marketing requirements. These pressures constitute a challenge for companies, to develop new technology and materials. In the long run, environmentally benign production may become a competitive edge. Environmentally benign production requires a shift of paradigm for engineers, accountants, government agencies, and many other parties. However, there is one line of development which is clearly emerging from the environmental requirements for manufacturing as a system: the object of study should not be restricted to a single plant or production facility, but should include chains or networks of production and physical distribution. Issues such as design for recycling, refurbishment, environmental costing, and many legal issues can only be studied if the scope of study is enlarged to the chain of value-adding activities, including ultimately end-of-life disassembly and refurbishment.

Today progressive manufacturing companies are developing a total life cycle approach to their products [5]. One multinational supplier of telecommunications equipment and services to the European market has developed a “Product Life Cycle Management” program which currently includes six major activities, namely: design and technology, purchasing of supplies and materials, manufacturing processes, waste reduction and energy management, packaging and post consumer materials management. This company now includes environmental considerations as part of its supplier qualification process. The “post consumer materials management” activity represents a long-term challenge but is based on the following ideas: in the near future, manufacturing will refurbish and reuse products and recycle as much of their contents as possible; finally companies will source new markets for the recycled material and safely dispose of residual materials when necessary.

For some manufacturing companies the “recycle, refurbish and resale” process has already begun. A recent article in The Economist (October–November 5, 1993, p. 99) reported that a UK company is producing and selling recycled and reconditioned motorcycles.

A major European-based computer manufacturer has developed a “Design for Sustainable Development” programme. This programme was developed in the early 1990s in response to three external influencing factors, viz. emerging international legislation, the need to maintain and increase customer satisfaction and finally an attempt to secure competitive advantage in the market. This company found that certain key customers were refusing to purchase consumables from it until it had implemented a return process. (Examples include laser printer toner kits.) Furthermore, other customers were requiring the reuse and return of product accessories in order for the company to qualify as a key supplier. The company is convinced that it will develop a competitive advantage over its rivals through its “Design for Sustainable Development” programme. This programme focuses on “waste management”, through waste reduction at the source, design for disassembly and maximising the opportunity to recover materials through reuse, recycling, reclamation, resale, reconditioning and remanufacturing. This company has already developed a “Waste Management” infrastructure, which in-
cludes an operating special-purpose facility in Europe to take back computers from key customers and recycle, reclaim, refurbish and resell them.

The value chain is a useful model to express the business and organisation structures now emerging. It is also a useful model from the point of view of environmentally benign production, and that of globalized competition. We identified earlier a trend towards product–customer integration in the value chain (see Fig. 1).

The chain of value-adding activities has been described systematically by Porter [6], who introduced the term value chain. According to Porter, the activities of a company can be distinguished into value-adding activities and supportive activities. The value chain can be depicted together with the points where supporting activities are linked. Value chain analysis provides a tool for investigating whether a company or a network of companies puts this effort at the right place in the chain, or whether there are attractive alternatives.

To demonstrate some changes in the value chain, consider Fig. 3. Suppose that the contribution of each element to the added value of the final product is normalised to 100%. We will discuss the consequences of the above trends for the value chain in two steps. First, we will elaborate the consequences without paying attention to the pressure for environmentally benign production. Secondly we will add this pressure to our analysis. In the first step (Fig. 3) we neglect the effort of, for example, increasing transportation costs. Then Fig. 3 suggests five effects:

- New materials such as highly alloyed steel, composite materials etc. will probably lead to an increase in value added in material supply. Material costs are rising in the long term, although in the short term the prices are determined by the general economic conditions and the particular situation in a particular industrial sector. However, nearly all metals, oil-based products and minerals are becoming more scarce and therefore more expensive in the long term.

- The situation with component manufacture is complex. Increased functionality of components in electronics results in expensive but high-value-added components. High-function components mean reduced inventory logistics and space requirements. The multi-function component eliminates the need for assembly so the value added in assembly is passed back to the component stage.

- Assembly is likely to move towards lower added cost also, because much functionality is already available in the components.

- Physical distribution will probably involve lower costs if the interaction between the customer and the manufacturer becomes more intensive.

- Improved service around the product will in-

![Fig. 3. Changes in the value chain.](image-url)
crease the added value in sales and after-sales activities.

At first glance, Fig. 3 might suggest that the industry should not put much emphasis on component manufacturing and assembly. However this would be a great mistake. In component manufacturing, there is a technological trend towards manufacturing systems where the marginal costs of an additional unit is almost zero. Miniature products and software products are good examples. But more generally, all knowledgeware (books, entertainment, NC codes, multimedia applications) has a marginal cost of almost zero. Note that components such as integrated circuits or software represent a considerable part of the added value of many of today’s products. Thus, the expected decrease of manufacturing costs is largely a matter of how investments costs are allocated to products. This leads to an important conclusion: if considerable investments are required for component manufacture, then the party which has made these investments controls the supply chain. This is simply due to the fact that this party can manipulate prices, delivery times and volumes. Therefore, high investment in component manufacturing (including software) should not be left to other parts of the globe if monopolies are likely to occur.

The case of assembly is different. Today’s assembly techniques are still largely manual. However, the costs of assembly are often reduced by more intelligent design of components. Furthermore, assembly has become more customer-order driven and therefore adds to the customer-friendliness and flexibility of the manufacturing system and its products.

In Fig. 4 we show the likely consequences of environmental costing. These effects should be superimposed on the effects of Fig. 3. No doubt, there will be considerable variances between different industries with respect to these figures. They do not pretend to have universal validity as a scientific law. Rather, these figures indicate the type of value analysis which it is worthwhile to perform for each branch of industry separately.

Fig. 4 shows first of all that environmentally benign production increases costs—at least in the first few years. Ideally we should avoid the situation where environmental costing is applied in one part of the world and not in other parts. Secondly, Fig. 4 suggests that environmental costing will give rise probably to higher costs of purchased materials and in component manufacturing. However, the environmental consequences of these manufacturing activities have been monitored for several decades, and it should be possible to compute these effects in any system of environmental costing. It is more difficult to estimate the effects of recycling of materials and components to the suppliers.

Fig. 4. Effect of environmental costing on value added.
For the same reason, it is difficult to estimate the situation in assembly. There is likely to be a considerable increase in the costs of assembly, because this is the phase where the costs of reuse or disassembly will probably be allocated in most cases. Thus, Fig. 4 gives additional insight into the nature of cost changes to be expected, but it does not change the main trends. These trends have been discussed above and will be summarised now:

- Competition in the manufacturing industry will be globalized.
- Product life cycles will be shortened, even if the life of individual consumer goods will be prolonged.
- The added value in physical transformation is declining. Its marginal costs are sometimes almost equal to zero.
- Sales and manufacturing will be re-integrated, either by direct marketing, or through customer-driven production.
- The object of study ("The Manufacturing System") will be the total value chain, rather than the factory.

In fact we will go further. We believe the manufacturing system must now be seen in the context of the value chain. We term this the extended enterprise. If the challenge of CIM in the past was to realise integration within the factory, the challenge to manufacturing now is to facilitate inter-enterprise networking across the value chain.

3.2. Inter-enterprise networking

Inter-enterprise networking encompasses the compression of "concept to customer" lead-time, working with just-in-time supply chains and logistic support throughout the product life. Against a background of accelerating specialisation and the visual disintegration of previously integrated businesses, these trends drive the requirements for elements of integration such as electronic data interchange to new levels of complexity. The Extended Enterprise, where core product functionalities are provided separately by different companies who come together for the purpose of providing a customer-defined product/service is made possible and viable through these technologies [7].

Referring to electronic data interchange and to the emerging integration of computing and telecommunications technologies, Keen [8] uses the terms "Reach" and "Range". Reach is the
extent to which one can interact with other communication nodes in the limit it becomes anyone, anywhere. Range defines the information types that can be supported from simple messaging between identical platforms to any computer-generated data between any operating platforms (Fig. 5). Electronic mail available to all members of a single department offers the lowest level of technology integration. Until recently extending reach across other parts of the company and particularly beyond the company has been both technologically difficult and expensive. Extending range requires a good definition of business processes. Tools and organisational approaches are now becoming available that make range extension viable. The driver to both reach and range increases is the enhancement of business degrees of freedom to respond to the volatile market place. The level of change in the market place requires that we have flexibility not only in product but in business structure and business processes as well. A high level of reach and range provides the business freedom to operate in the Extended Enterprise. The mapping of a company onto the range/reach chart gives a good indication of its scope for innovative business improvement through the use of integration technologies (Fig. 6). In the Extended Enterprise the bringing together of core competencies from many different organisations to provide a short manufactured life product means regular enterprise business process restructuring. The pressure on time scales means interactive decision support is required. Companies without appropriate reach and range will not be able to participate in this Extended Enterprise business system. Technology integration price/performance improvements will greatly reduce price entry barriers to all companies world wide. In the past high reach/range has been recognised as valuable but has been only available in specialist applications.

Some industry sectors have invested extensively in providing themselves with an industry-specific capability. This expensive option is well illustrated by the automotive industry. In the manufacturing arena pan-national competitive edge can be provided by access to creative information processing centres such as specialist design or manufacturing houses. The evolution of such systems is already apparent in niche product areas: the European Airbus, Tornado, the European Fighter Aircraft (EFA) and NH-90 Helicopter projects are good examples which typically handle 100,000 parts per aircraft. This technology will rapidly become appropriate, affordable and desirable for a broad spread of business enterprises as the dramatically declining information technology to labour cost ratio is maintained. Even the communications costs may be insignificant. In fact the challenge of the integrated enterprise is not really a technical one, far more a challenge to management. Power via conventional hierarchy is seriously weakened by the flat structure of the telecomputing inter-enterprise environment.

This management challenge is a deviation from a tradition in information technology which views standards, architectures and even non-technical standards for business interchange as purely technical issues. The reality is that businesses require electronic alliances to create value-adding partnerships. It is no longer possible or even desirable to embrace world class capability in all the key functional areas wholly within the organisation. Class leading competitiveness flourishes in an environment of dependency and interdependency with other providers of components, services, ideas. Inter-enterprise networking offers this capability.

The United States Department of Defence initiative CALS—Computer-aided Acquisition

Fig. 6. Scope for business improvement through integration.
and Logistics Support—will impact many European companies. It is likely that, together with the European initiatives, this will influence the standards and the pace for inter-organisation technical communication. The market place to which manufacturing businesses, business integration researchers, their teaching and their facilities must respond includes:

- Business processes which cross enterprise boundaries to interface with functional areas in other companies, for example, product design or manufacturing process definition.
- Supplier/customer integration (people and processes) through interchange of commercial/technical data.
- Ability to function effectively as links for information and product in unbuffered supply/distribution chains.

The ability to network the activities of a number of entities to produce and sell manufactured products profitably depends on the relationship of these entities and the communication that passes between them (Fig. 7).

We are accustomed to thinking about this in the context of a single enterprise with different departments, Sales, Design, Engineering, Manufacturing, Distribution etc. However, within a global market-place, entities from many different enterprises, or entities which in themselves are nominally independent enterprises, relate via a single product to produce a designed result. An example might be a merchandising entity recognising a business opportunity and requesting:

- a design entity to design it;
- a manufacturing entity to build it;
- a distribution entity to distribute it; and
- a marketing entity to sell it.

The implication of such an example is that all the entities can be considered as "flexible" or "programmable" within their expertise envelope.

3.3. Issues in the extended enterprise

In the context of the extended enterprise and the need for inter-enterprise networking, it seems to us that there are five issues which should be emphasised.

- Firstly there is the fact of reduced product life cycles and the consequences in terms of flexibility in the manufacturing capability.
- Secondly there is the issue of time-based competition and the associated need to reduce the time to market for new products.
- Thirdly there is the necessity of taking a total product life cycle view due to the heightened awareness of environmental problems.
- Fourthly there is the challenge of creating organisations and systems which attract high-quality people and make full use of their capabilities.
- Finally there is the problem for the individual manufacturer of developing a manufacturing strategy which is appropriate to the business environment and which takes account of the position of the manufacturing facility in the value chain.

We will now review each of these issues in more detail.

3.3.1. Product life cycle

The notion of stability in manufacture with standard products built on standard systems for extended periods can now be viewed in context: a brief, and exceptional time which rose to prominence in the immediate post war period, chiefly in the USA. Stability is not normal. The natural environment encourages variety, short life, niche habitats, customisation. This was the case in manufacturing before the mid part of this century. Special circumstances and technological con-
Constraints changed the basis of competition in many markets between 1940 and 1960. The "natural" order has now re-imposed itself. Customer awareness of technological development on a global scale, electronic communications, close coupling of the customer to the manufacturing source have all led to reduced product life cycles. Overriding this is the competitive position faced by all manufacturers who have to satisfy changing customer preferences.

In the late seventies and early eighties the concept of flexible manufacturing systems was widely publicised. The system which resulted serviced an environment where product life had fallen below manufacturing facilities life. It was becoming increasingly difficult to justify dedicated single-product automated manufacturing facilities. Flexible manufacturing systems exhibited a relatively high degree of transient flexibility compared to hard automation. Many systems had the ability to process more than one product type or family. This state flexibility must not be confused with the emerging requirements imposed on manufacturing facility provision by current developments in product life cycles. Pure one-of-a-kind engineer and manufacture to order remains a small market opportunity but custom build of options to order on a common product platform is a rapid growth area. It potentially embraces clothing and consumer durables as well as regular customised products. For standard products short life is coupled with the requirement to bring high volumes of newly specified, fully conforming product to market near instantaneously with the release of specification to production.

Engineered products have an increasing proportion of their added value provided by software or design features. The reproduction costs of say a software-derived feature are not volume sensitive. But market price is highly time sensitive. So viability in the face of high development costs requires high volume capability at start up. The demand curves of product introduction, maturation, decline, increasingly resemble a square wave form.

Environmental concerns raise the rate of new product and process introduction to cope with legislation. Increasingly we may experience customer rejection of non-recyclable/non-upgradable products. We will see short manufacturing product life coupled with extended field life and return to plant for upgrading, perhaps reprogramming.

The effect of all these developments is to raise the requirement for flexibility in manufacturing capability to new heights, and to impose a high degree of uncertainty into all aspects of the manufacturing process. These requirements can not be met by incremental developments to existing research directions.

The flexibility required by manufacturing requires enterprise agility and access to external resources through the extended enterprise. This will place special requirements for plug compatible process planning systems. The physical manufacturing plant and its control systems—both process control and production control—will have to be reconfigured as an ongoing activity. There will be little opportunity for learning by error. The manufacturing organisation will have to adopt the style of the learning organisation. Training systems will be an integral part of workplace fitness. This rate of change will pose problems for performance measurements and costing systems. New metrics will be needed. Similarly manufacturing strategy and investment decisions will be rapidly degraded by time. Support tools and near-real-time reassessment will be a requirement.

Metrics are important. Metrics or measures of performance provide milestones against which performance can be evaluated. However measures of performance also serve to influence, oftentimes to direct behaviour. The measures of performance must therefore reflect well the objectives of the manufacturing system. Frequently, in the past certainly, a preoccupation with one measure, namely cost was often to the detriment of others such as quality, responsiveness etc.

3.3.2. Product concept to manufacture—Time to market

Recent findings have highlighted the relative success of companies who successfully reduce time to market (see Table 1).
Table 1

<table>
<thead>
<tr>
<th>Time to market</th>
<th>Winners</th>
<th>Losers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile design</td>
<td>3 years</td>
<td>7 years</td>
</tr>
<tr>
<td>Computer design</td>
<td>9 months</td>
<td>4 years</td>
</tr>
<tr>
<td>Retail clothing</td>
<td>36 hours</td>
<td>6 weeks</td>
</tr>
</tbody>
</table>

Best practice in the field stretches the advantage of time-based competition still further. In 1985 the Japanese automobile industry worked at 42 months for the new product introduction cycle. Currently they are planning for 24 months and substantially increasing the number of new products being introduced. Many European and US successes have been realised through rapid product introduction programmes. For example, in the process industry, Proctor and Gamble have reduced their time to market for new products by 50% since 1987.

The most extreme cases arise from military products. Traditionally military products demonstrate extended product development time. Yet paradoxically the industry has exhibited "impossible" performance. A recent European example is the design, development, implementation and staff training to allow in-flight refuelling capability on 20+ year old aircraft. This enabled the British to service their troops in a dispute with Argentina. The "time to market" for this complex system was less than 2 weeks. More recently in the Gulf War a new type of bomb was required to penetrate command posts encased in concrete and buried 30 m underground. Texas Instruments used a team of 18 engineers to complete in 1 week, complex wind tunnel and simulation tests normally allocated 18–14 months. The time between customer request and delivery of product in the field was 1 month. Normal time is 2.5 years.

These military examples are undertaken without regard to cost—in fact usually ahead of cost authorisation. Yet the net effect is better products in greatly reduced time at substantially less cost than the normal development process. The accelerated time to market process is not risk free. In Japan only 1 in 4 products launched on the domestic market are developed for sales outside Japan. Yet fast time to market does not automatically lead to expensive product development programmes. Many practitioners report reduced costs and better products.

Clark (reported in [9]) argues that lean product development techniques simultaneously reduce the effort and time involved in manufacturing. Lean product development techniques based on project leadership, teamwork, good communications and simultaneous development/engineering, have had tremendous consequences in the auto industry. Clark and Fujimoto [10] illustrate the impact of lean design, as practised by Japanese auto producers compared to their European and American competitors.

The strategic impact of compressed time to market on manufacturing organisations is far reaching. Largest profits are available to those early in the market. In 1987 Clark and Fujimoto [10] showed that each 1 day delay in introducing a new mid-size car on the international market represents at least 1 million ECU in lost profits. A separate study found that, amongst leading companies, operating in competitive markets, a 50% overspend on product development results in a 3–4% drop in life cycle profits. A 6 month delay in time to market causes a 32% drop in profit.

The relationship between the price that the market will bear and time is heavily skewed in favour of early availability in the market. Heavy discounting of products only a few months old is common. Late producers may never have a profit harvesting phase. Opportunities do exist for suppliers choosing to come late into the market. These opportunities arise from the increasingly mechatronic nature of many products. The high ratio of added value through design means that replication of developed products bears a very low additional cost. Late into market producers can capitalise on this if they can rapidly reproduce products developed by others. Either way, for new product producers or "clone" product producers, time to market is crucial. The fast producer can proliferate variants, create market segmentation and generate profit potential. Fast to market producers are in fact lower-risk pro-
ducers. They have multiple opportunity for interactive, low-risk, developments all of which are customer driven. Their fast processes are usually highly controlled, cost-effective processes.

The emerging time to market challenge can be likened to an earlier manufacturing systems challenge—material control. In the past material control was crucial to manufacturing success. Now manufacturing is as much an idea system as a material processing system. The generation, communication and application of ideas and their application in products is the core of fast time to market. The manufacturing system must be open to idea input: hence increasing reliance on the extended enterprise including customer input.

Communications and empowering of individuals shift the demands on both organisation structure and enterprise to interaction. Extra life cycle values and requirements for design integrity backed by deterministic process in manufacture demand a new generation of concurrent engineering support tools.

3.3.3. Total product life cycle view

It is an interesting paradox, referred to earlier and repeated here, that we are likely to see short manufacturing product life coupled with extended field life and possible return to plant for upgrading, perhaps reprogramming. There is definite pressure on the manufacturing system to take responsibility for the total life cycle of a product, including the environmental effects and the costs of disassembly, disposal, or refurbishment. The ultimate aim is complete reuse of materials in order to obtain manufacturing systems which are neutral with respect to the environment.

Issues to be taken into account here are:
- legislation with respect to environmental side effects;
- environmental costing;
- lack of virgin materials in the long run;
- consumer’s rejection of products where recycling has not been made possible.

The current response to the above challenges, is to focus primarily on the product development process. Many product development departments at different companies are performing studies for multi-life-cycle usage of components. These studies are combined with manufacturing engineering studies to develop production processes where harmless end-of-life disposal, disassembly or refurbishment is facilitated.

In combination with these studies, new forms of economic and legal trading conditions must be investigated, such as:
- Lease of commodities in place of purchase, i.e. the ownership rests with the producer.
- Upgrade of modules of an installed base in such a way that modules are recycled and reused, whereby the installed product is continuously refurbished. Such a policy goes together with new methods of payment for products during the period of product usage by customers.
- Tracing and tracking of individual products which are difficult to identify, such as fresh food or household commodities.

The challenge lies in creating manufacturing systems which do not affect the environment; and the current response lies in charging the engineers primarily with finding solutions. This situation creates two difficulties, an immediate difficulty and a more fundamental difficulty. The immediate difficulty is that the product and process development engineers do not have a design methodology (or even experience) available to satisfy these new constraints. Quite often, basic information about environmental impact is simply not available. A more fundamental difficulty, however, lies in the fact that almost every function in society has to change its paradigm. Not only engineers, but also lawyers, accountants, politicians, investors, consumers will be confronted with the consequences of the requirements for environmentally benign manufacturing systems. This shift of paradigm of nearly all parties involved in the business, increases the uncertainty of the engineers in charge of finding better technological solutions. We believe that this shift of paradigm is in itself too complicated to be treated here in the same way as the other issues of this paper. We suggest that a separate paper be devoted to this point.

Enterprises involved in the production of physical goods will need access to very well educated
people to solve the problems of environmentally benign manufacturing. This has a number of consequences for these enterprises, but also for the society as a whole. Enterprises should be aware of the fact that excellent employees are the ultimate source of global competitiveness, in the long run. This means that manufacturing should provide good working conditions and abandon its image of dirt, repetition, and anonymity. High-quality jobs should be provided, in a clean, attractive and safe setting, challenging the employees with a high rate of change in technology. Society as a whole should provide education programs in technology which make technology attractive to young people. These programs should enable students to become product- and process-development engineers for whom continuing education in other fields (including law and economics) is completely natural.

3.3.4. High-quality organisations and people

High-quality organisations and people constitute the fourth key element in the future of our manufacturing system. To attract high-quality organisations and people, industry has to fight several battles.

First of all, industrial work has a connotation of being laborious and tedious. Industry and education should co-operate to improve this image. A career in manufacturing technology should be perceived as challenging, rewarding, and innovative. Societal welfare is largely due to manufacturing technology, and in particular its output.

Second, it is unlikely that inter-enterprise networking can be obtained without a shift of paradigm in the work organisation itself. It seems that industry will move towards the management of knowledge, rather than the management of physical assets. The hierarchical paradigm of organisations with its focus on vertical command chains will probably be replaced by a networking paradigm with the focus on horizontal communication.

The hierarchical authority systems prevalent in vertically integrated industrial firms are slow to identify rapidly changing customer requirements and to react quickly with creative product offerings. Large hierarchical organisations, which maintain clear boundaries between functionally based departments and separate the tasks of work planning and design from those of work execution, tend to be good at task-specific innovation but have great difficulty in working across departmental boundaries to generate innovative products quickly.

The networking paradigm, where teams of self-organising and self-directing groups co-operate across the value chain, offers the possibility of fast creative product response, because each link in the chain understands how its activities add value to the customer. The teams are capable of self-direction precisely because they understand customer needs. In an important sense, the voice of the customer provides the direction which was provided by layers of management and supervision in large vertically integrated industrial enterprises.

Thus we can say today's focused factories have organisationally flat structures. Within these focused factories, management seeks to dissolve the boundaries between, on the one hand, those who plan and design work and, on the other hand, those who execute work and to create cross functional teams. These cross-functional teams seek to develop relationships with suppliers and customers.

Today's manufacturing organisations focus on products and product families. They seek to adopt where possible, a product-oriented manufacturing layout and organisation. It seems that the need to provide a customer focus is the main motivating force behind product-oriented layout.

Earlier we indicated that the role of the supervisor has been greatly changed and that in the future, as organisations become flatter, the number of supervisors will greatly reduce. As we suggested the customer is becoming in a very real sense the supervisor. Those few supervisors who remain will have very different roles than heretofore. They will consult, persuade, communicate, support fast information flow, rather than direct and control operators.

Learning is another aspect of future organisational forms. In earlier days, Computer Integrated Manufacturing was assumed to yield factories which would no longer employ humans. How-
ever, humans have never been absent in manufacturing. Improvement in manufacturing follows learning curves, and these learning curves stop if completely automated machinery comes into play. Consequently, we should think of manufacturing as a system of continuous change and improvement, rather than as a machine which repeats itself. Future manufacturing enterprises should become learning organisations [11]. In an environment of rapid product change, frequent new product introduction and customisation to individual customer needs, the retention of knowledge generated in earlier designs and customer orders is important. The ability to reuse knowledge is critical to achieve rapid response to market and customer order changes.

The concept of organisational learning was developed in the 1960's. Later it was recognised that for an organisation to survive its rate of learning must be equal to or greater than the rate of change in the external environment. Here learning is not merely the retention in the organisation of data but the ability to develop from the data information, using past mistakes, so that the organisation is truly responsive to the business environment.

The realisation of the learning organisation is partly achieved by the recognition of the need for it. Psychology of direction can then encourage and focus effort on making it happen. Alongside this we need new business metrics. If knowledge is vital to the successful enterprise, we need to be able to measure it and even assess knowledge use or turnover in a similar way to the importance we currently attach to physical stock turnover as a business metric.

A learning organisation is not the same as a collection of learning individuals. An organisation may easily fail to recuse its knowledge, although the individuals do learn. Of course, individual learning is a necessary condition for a learning organisation and is facilitated by combining work design and planning with execution. However, organisational learning is primarily concerned with co-operation. As such, learning organisations will be suitable for inter-enterprise networking.

3.3.5. Developing a manufacturing strategy

The 1990 International Manufacturing Futures Survey identified manufacturing strategy determination as an important topic for manufacturing companies. Based on a survey of manufacturing enterprises in three regions, namely Japan, the United States and Europe this report [3] concluded that: "... the factories of the future in each region are all focused on the development of organisations in which manufacturing strategy is tightly linked with the business strategy. All three regions report a high emphasis on the linkage between manufacturing's functional strategy and the overall business direction. This result signifies recognition of the manufacturing function's strategic importance in an increasingly competitive global marketplace".

This recognition of the importance of manufacturing strategy determination is not new. For example Skinner argued that: "... 40% of any manufacturing based competitive advantage comes from the long term planning of the manufacturing strategy, involving decisions pertaining to the number, size, location and capacity of facilities and the basic approach to materials and workforce management. Another 40% comes from major changes in equipment and process technology, while the remaining 20% emanates from narrow operational cost—reduction parameters for productivity. In effect 80% of the advantage is achieved by the determination and implementation of good strategic decisions. Unfortunately very little focused research has gone into ensuring that methodologies, frameworks and models are available to assist managers to make good strategic decisions".

The Society of Manufacturing Engineers (SME) [12] in the US also argue for increased emphasis on the development of manufacturing strategy. They argue that: "Manufacturing of future products will differ dramatically from today. How raw materials are converted and transformed will become a more strategic decision. This decision will become more complicated in terms of what to make or where to buy in a world that is becoming a huge, single economy... Strategic alliances between companies, co-oper-
ative production agreements, advanced processing technologies and their justification, and numerous other factors will be added to an increasingly complex manufacturing equation’.

In fact the SME go further and suggest that the manufacturing engineer of the future will have multiple roles, namely that of technical specialist, operations integration and manufacturing strategist.

It seems to us that in the context of the extended enterprise, strategic manufacturing decisions will be difficult to make. Furthermore the costs of poor decisions will be extremely high. Finally it is worth noting that whereas much research work has been reported on the content of manufacturing strategy, little work seems to have been done on the process of manufacturing strategy determination, and there are few if any generally accepted methodologies or tools available to support this process.

3.3.6. Overview

We have now outlined our ideas on the important issues which arise in the movement towards the extended enterprise. Of course the extended enterprise will not arise following a major design initiative. It will evolve over time. Already elements of it can be seen in some industrial sectors e.g. the supply chain networks emerging in the European automotive industry. In fact in our view this movement towards the extended enterprise model of operation is now well underway in industries such as information technology, telecommunications, aerospace and automotive. We will now go on to briefly consider the evolution of manufacturing enterprises towards this extended enterprise model.

3.4. Towards inter-enterprise networking

For the past ten years manufacturing systems specialists have evolved a series of approaches to the design and operation of manufacturing systems. In our view, the drive to inter-enterprise networking represents an extension and a synthesis of many of these approaches. Approaches, listed here in order of their development such as MRP, JIT, EDI, WCM, Concurrent Engineering, Lean Production, Benchmarking and Business Process Redesign, essentially synthesise into the Inter-Enterprise Networking model. In this section we briefly outline these approaches and argue that they culminate in Inter-Enterprise Networking.

The ideas of MRP, originally developed by Orlicky of IBM in the 1960s, were important not least because they taught us the importance of hierarchical planning and the involvement of many department and functions within manufacturing to solve materials planning and control problems. Later in the late 1970s and early 1980s, JIT ideas, originally developed in the Japanese automotive industry, became known in Europe and the U.S. JIT emphasised customer involvement in the final scheduling of production systems and close co-operation with suppliers to achieve quality and timely delivery. Thus already in the early 1980s JIT began to focus the view of manufacturing systems specialists on issues outside the four walls of the manufacturing plant, viz. customer requirements of timely delivery and supplier involvement.

In many ways the ideas of the WCM (World Class Manufacturing) school (see for example Schonberger [13]) developed from the experience of JIT implementation studies in the USA. Issues of continuous improvement, training of people, integration of product design and process design to facilitate efficient manufacturing were also emphasised. Hayes, Wheelwright and Clark [14] for example identified the key characteristics of world class manufacturing as follows:

1) Becoming the best competitor. “Being better than almost every other company in your industry in at least one aspect of manufacturing.”

2) Growing more rapidly and being more profitable than competitors. World-class companies can measure their superior performance by “observing how their products do in the marketplace and by observing their cashbox”.

3) Hiring and retaining the best people. “Having workers and managers who are so skilled and effective that other companies are continually seeking to attract them away from your organisation.”
(4) Developing engineering staff. "Being so expert in the design and manufacture of production equipment that equipment suppliers are continually seeking one's advice about possible modifications to their equipment, one's suggestions for new equipment, and one's agreement to be a test site for one of their pilot models."

(5) Being able to respond quickly and decisively to changing market conditions. "Being more nimble than one's competitors in responding to market shifts or pricing changes, and in getting new products out into the market faster than they can."

(6) Adopting a product and process engineering approach which maximises the performance of both. "Intertwining the design of a new product so closely with the design of its manufacturing process that when competitors 'reverse engineer' the product they find that they cannot produce a comparable one in their own factories without major retooling and redesign expenses."

(7) Continually improving. "Continually improving facilities, support systems and skills that were considered to be 'optimal' or 'state of the art' when first introduced, so that they increasingly surpass their initial capabilities." Hayes, Wheelwright, and Clark also go on to say that "the emphasis on continual improvement is the ultimate test of a world class organisation".

Meanwhile the proponents of Concurrent Engineering (CE) begin to emphasise the issue of product design time and to research business, technological and organisational themes in order to reduce time to market. It is interesting that one of the important themes in CE is the development of standards to support the exchange of product data between the CAD system of suppliers and their customers. The work on CE is of course ongoing within the ESPRIT and BRITE-EURAM programmes of the CEC and the CALS initiative in the USA.

EDI technology emerged in the late 1980s. Initially used to support business transactions (invoicing, purchase order call off) between suppliers and their customers, it is now beginning to be used to exchange technological product data. Today's most advanced manufacturing companies use EDI to exchange production and purchasing information and to support joint (with suppliers and/or customers) engineering development teams.

Womack et al. [9] defined "Lean Production" as the successor to mass production. Like mass production, the ideas of lean production were initially developed in the auto industry. Mass production arose in the USA in the early 20th century in the Ford Motor Company. Lean production developed initially in the Toyota plants in Japan at the end of the 20th century. Clearly our ideas on Lean Production are still under development.

According to Jones [15] the essential characteristics of Lean Production can be summarised as follows:

(1) It is customer driven, not driven by the needs of manufacturing.

(2) All activities are organised and focused on a product line basis led by a product champion, with functional departments playing a secondary, servicing role.

(3) All activities are team based and the organisation is horizontally and not vertically oriented.

(4) The whole system involves fewer actors, all of whom are integrated with each other—330 engineers in the product-development team versus 1400, 340 suppliers versus 1500, about 300 dealer principals versus 3600 (to sell 2 million vehicles) and 2000 assembly employees versus between 3000 and 5500 (for plant assembling 250,000 units a year).

(5) There is a high level of information exchange between all the actors and a transparent and real cost structure.

(6) The activities are co-ordinated and evaluated by the flow of work through the team or the plant, rather than by each department meeting its plan targets in isolation.

(7) The discipline necessary for the system to function and expose problems is provided by JIT and Total Quality in the plant and supplier and dealer performance evaluation.

(8) Wherever possible responsibility is devolved...
to the lowest level possible, in the plant or to suppliers.

(9) The system is based on stable production volumes but with a great deal of flexibility.

(10) Relations with employees, suppliers and dealers are based on reciprocal obligations that are the result of treating them as fixed costs.

Thus Lean Production addresses product strategy, product development, the supply chain, manufacturing and product distribution. Essentially it addresses many issues in the value chain, which results in a networking of customers, assemblers and suppliers.

In more recent years Benchmarking and Business Process Redesign have emerged. The central idea of benchmarking is to decompose a business into its essential processes, identify examples of best practice for each of these practices and then define an approach to achieve best practice. Thus benchmarking seeks to improve existing processes. Business process redesign (sometimes termed business process re-engineering) offers a more radical approach. It seeks to identify each business process, question its relevance to the achievement of business objectives and redesign the overall business to incorporate only appropriate processes. In fact benchmarking may well be used following business process redesign to identify and achieve best practice for each individual process. For a detailed discussion on business process redesign and benchmarking see Hammer and Champy [16]. It is worth noting also that most of the work on benchmarking and business process redesign was done in the USA. Also the software tools for business process redesign come primarily from North America.

Earlier, in Fig. 6, when we looked at the impact of information technology (IT) on business and manufacturing systems, we suggested that business process re-engineering is necessary as we expand the reach and range of information technology.

Clearly many of the ideas and approaches outlined here support the manufacturing enterprise in its evolution towards the integrated enterprise model we have defined earlier. However the Integrated Enterprise represents a quantum leap for manufacturing systems. The changes which it requires are so far reaching that, in our view, research and development work is necessary if manufacturing companies are to be successful in the 21st century.

4. Conclusions

Manufacturing systems are subject to tremendous pressures from the need to match global competition entering previously local markets, to develop environmentally benign products and production processes and to develop new forms of business organisation. Along with these pressures, five major trends have been identified, namely:

(1) The fact of reduced product life cycles and the consequences in terms of flexibility in the manufacturing capability.

(2) The issue of time-based competition and the associated need to reduce the time to market for new products.

(3) The necessity of taking a total product life cycle view due to the heightened awareness of environmental problems.

(4) The challenge of creating organisations and systems which attract high-quality people and make full use of their capabilities.

(5) Finally there is the problem for the individual manufacturer of developing a manufacturing strategy which is appropriate to the business environment and which takes account of the position of the manufacturing facility in the value chain.

Given these pressures and trends, it is no longer feasible to look in isolation at the manufacturing system. The manufacturing system must be seen in the context of the total business and the linkages of the business back through the supply chain and forward into the customer chain. The challenge for the future is to consider the extended enterprise and facilitate inter-enterprise networking across the value chain. This concept of inter-enterprise networking is called the extended enterprise for short.

The above mentioned pressures and trends, as well as the response of the extended enterprise, require considerable research effort. Clearly the
extended enterprise model will not be realised overnight. It will evolve over time. Already elements of it can be seen in some industrial sectors. Indeed programmes such as JIT, World Class Manufacturing (WCM), Lean Production; processes such as Business Process Redesign and Benchmarking; and technologies such as computer networking and EDI allow, in their various ways, manufacturing enterprises to move in the direction of inter-enterprise networking.

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