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The Evolution of Agile Manufacturing

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The Evolution of Agile Manufacturing

Abstract

This paper provides an exploration of the concept and content of Agile Manufacturing. It describes the nature of the content of AM and synthesises the literature to propose a comprehensive definition of purpose and process. Real Agile Manufacturing (RAM) is viewed as a strategic process; it is about surviving and prospering in the competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets. The paper argues that RAM is evolutionary, in that it is development from existing systems of management and technologies. However it is also revolutionary because the full application of RAM involves a departure from existing systems.

RAM is shown to be built upon based upon four fundamentals. First, each partner must benefit, thus multiple winners (manufacturers, suppliers, customers) is the objective. Secondly, integration (recourses, methods, technologies, departments or organisations) is the means of achieving RAM. Thirdly IT is demonstrated to be an the essential condition, finally core competence is seen to be the key.

Keywords: agile manufacturing, real agile manufacturing, framework, integrate, IT, core competence, multiple winners.

Introduction

The purpose of this paper is to explore the evolution of agile manufacturing to further our understanding of process and content. It is argued that agile manufacturing represents the continuing development of manufacturing responses to competitive pressure. Accordingly the paper begins by charting the developments leading to the adoption of agile manufacturing to show how these precursors formed incremental stepping stones. These stages are demonstrated to be driven by competitive pressures, so that the outcome, agile manufacturing, is shown to be the culmination and current epitome of manufacturing's competitive response. Agile manufacturing is evolutionary in as much as it is a logical progression from existing manufacturing systems (McCarthy and Ridgeway, 2000). Ironically our analysis shows that although agile manufacturing is a competitive response, it is enabled by co-operation. Paradoxically it is also revolutionary in that the new

integrated combinations of competencies and technology, which create collaborative advantage, represent a radical departure from existing systems. We find that agile manufacturing is a strategic process which has the objective of creating multiple winners (suppliers, customers and partners); that the mechanism is the integration of core competencies whilst the application of information technology is an essential condition. The contribution of the paper is two fold. First our exploration of the elements involved leads a fuller appreciation of the dynamics of agile manufacturing. This can be seen as a response to Sharp *et al's* (1999) recent comment, that there is a need to identify the menu of agility enhancing activities from which corporate leaders can select those items appropriate to their own companies. Secondly, our analysis provides a richer conceptual understanding of the radical changes wrought by agile manufacturing.

The context of competition

Success in manufacturing, indeed even survival, has become increasingly difficult (Zhang and Sharifi, 2000). Competition has intensified from a national scale to a global arena, product life cycles have shrunk, yet there is an escalating requirement to satisfy the specific and individual needs of customers. Thus where once a manufacturer's success could be measured by their ability to cost-effectively produce a single product, success now has to be measured in terms of flexibility, agility and versatility. In short, the ability to handle continuous improvements and change. Consequently the changes in markets, customer requirements, technology (Bhandarker and Nagi, 2000) have become the competition criteria (Sharp *et al*, 1999, Zhang *et al,* 1999), and are now the critical factors in determining manufacturing success. These rapid environmental changes have forced companies to improve their manufacturing performance in conditions of increasing uncertainty (Christopher, 2000). Significantly such changes are occurring faster and more unexpectedly than ever before (Sharifi, 1999). Fung *et al* (1997:365) put this well, "An enterprise is confronted with a continuous changing and unpredictable environment". Management development has responded to these competitive environmental pressures, in particular to the ensuing uncertainty and volatility (Christian *et al,* 1999, Montreuil *et al*, 2000), by developing new approaches, concepts and methods. The result is the increasingly rapid evolution of business systems and the creation of new manufacturing and management philosophies. As Sharp *et al* (1999) put it, "there are many manufacturing panaceas". Research by Womack *et al* (1990), Slack (1991), Hayes and Pisano (1994), Gilgeors (1999), has demonstrated that there are many different views about the ways companies can improve their manufacturing function to enhance their competitive advantage. Yet, despite the resultant variety in manufacturing research some recognisable tendencies are emerging. We note, for example, (1) In production systems, rigid manufacturing systems are gradually changing into a flexible manufacturing

system to improve the system's ability to respond to consumer's needs. (2) In organisation structures, large multi-level organisation structures have been reduced to a single-level network structure. Concurrent engineering and virtual have been introduced. (3) In computer management, single task applications have been transformed into computer integrated manufacturing systems (CIMS). (4) Finally, personnel issues, especially training, have become key concerns.

It can be argued that the driver of these changes is competition, but competition is itself an evolutionary process. The unrelentless evolution of competition means that last year's competitive advantage is rapidly lost as newer, sharper techniques and technologies are honed to provide tomorrow's competitive edge. We can see, in broad historic terms, how the original critical issue of competition was supply, which then moved to the product's price. The focus progressed to product quality (Christian *et al,*1999*)*; to improving delivery time (Perry *et al,* 1999*)*: to providing after sales service and currently to creating customer satisfaction.

To set this evolutionary process into context we should note how manufacturing systems have reflected and responded to changing patterns of consumer demand. The period immediately after the Second World War was characterized by relatively high demand and an inability to supply. Consequently, processing speed and price were the dominant manufacturing factors (Draaijer, 1992). This encouraged the extensive automation of production processes, resulting in mass production. The key objective of manufacturing became the mass production of goods at lower prices (Yusuf, 1999). During the 1980s, in response to emerging discriminating consumer preferences, companies pursued quality management. Concepts such as total quality management control (TQC), statistical process control (SPC), and quality function deployment (QFD) were developed and applied. Simultaneously, systems such as flexible manufacturing, lean production and world class manufacturing (Schonberger, 1986) were incorporated into production systems (Lindberg, 1990).

In 1991 the Iacocca Institute at Lehigh University, USA, presented an important report (Iacocca, 1991) on the new foundations of competition. They found that the critical manufacturing issues were continuous change, rapid responses, quality improvements and social responsibility. Agility, as a manufacturing concept, was coined.

The nature of real agile manufacturing

The Agility Forum at Lehigh University found that agility was driven by competition; the fragmentation of mass markets; co-operative production relationship; evolving customer expectations and increasing social

pressures. A range of publications about agility have followed the initial report. These papers argued that the crucial areas of change include the consumer, the competitor, technology and resources. Interestingly, and possibly a measure of the uncertainty surrounding agility, each article defines and explains agility in different ways. Accordingly, agile manufacturing has been defined in terms of the agile enterprise, products, workforce, capabilities and the environment which gives impetus to the development of the agile paradigm. The principal elements of the definitions presented can be summarised as follows:

- *Response to change and uncertainty,* Iacocca Institute 1991; Gould, 1997; Cho, Jung, Kim, 1996; Devor, Graves, Mills, 1997; Goldman, Nagel,, 1993 and Goldman, Nagel, 1995.
- *Building core competencies,* Gould, 1997 and Yusuf *et al*, 1999.
- *Supply highly customised products,* Iacocca Institute, 1991; Yusuf *et al*, 1999; Gould, 1997; Bullinger, 1999; Cho, Jung, Kim, 1996; Devor, Graves, Mills, 1997 and Goldman, Nagel, 1993,1995.
- *Synthesis of diverse technologies,* Iacocca Institute 1991; Kidd, 1994; Gould, 1997; Bullinger, 1999; Devor, Graves, Mills, 1997 and Booth, 1996.
- *Intra-enterprise and inter-enterprise integration,* Yusuf *et al*, 1999; Devor, Graves, Mills, 1997 and Booth, 1996.

In essence, we conclude that the concept of agile manufacturing embodies the ability to cope with change by the application of partners' core competencies to supply customised products. It requires the synthesis of diverse technologies within an integrated system.

Evolution or Revolution?

Two different views about the form of the agile manufacturing are portrayed in the literature, that it can be seen as either revolutionary or evolutionary. As evolutionary, it is progressive and incremental change or alternatively, as discontinuous and revolutionary. Some conceptual constructions emphasize incrementalism, whilst others focus on the discontinuity necessarily involved in implementing agile manufacturing. Our view, presented here, is that agile manufacturing has arrived as an evolutionary form of manufacturing system, most obviously because it synthesis and incorporates many prior approaches. Sharp *et al* (1999) argue convincingly that lean manufacturing and world class manufacturing are traditionally positions in an organisation's migration towards the ultimate goal of agile manufacturing. Consequently it represents an evolutionary "fitness", a refinement of what has gone before, but in a new, and integrated, recombination to fit the new competitive environment. Consequently, we also note the revolutionary aspect, not least in that agile manufacturing is very different from the preceding systems upon which it is based. For example, as Maskwell (1997) notes, lean or

world class manufacturing is being very good at the things you can control, but agile manufacturing deals with the things you cannot control. Table 1 provides a summary of the elements discussed in the literature which are seen as elements in this evolution of agile manufacturing.

Table 1 The evolution of interpretative definitions of agility

Author	Key words	Definition
Iacocca 1991	Capability, Real-time response, Customer needs	Agility means a manufacturing system with extraordinary capabilities (internal capabilities: hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the marketplace (speed, flexibility, customers, competitors, suppliers, infrastructure, responsiveness). A system that shifts quickly (speed, and responsiveness) among product models or between product lines (flexibility), ideally in real-time response to customer demand (customer needs and wants)
Goldman 1994	Strategic response, Irreversible changes, Dominant system,	Agility is a comprehensive strategic response to fundamental and irreversible changes that are taking place in the dominant system of commercial competition in "First World" economics.
Kidd 1994	Synthesis, Compatible CIM, TQC, MRP, BPR, OP	Agility is a synthesised use of the developed and well-known technologies and methods of manufacturing. That is, it is mutually compatible with Lean Manufacturing, CIM, TQM, MRP, BPR, Employee Empowerment, and OPT
Booth 1996	Vision, More flexible, Customers,	Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of "lean manufacturing". In lean manufacturing, the emphasis is on cost-cutting. The requirement for organisations and facilities to become more flexible and responsive to customers led to the concept of the "agile" manufacturing as a differentiation from the "lean" organisation.
Cho 1996	Capability, Competitive Environment, Customer-designed,	Agile manufacturing can be defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services
Gould 1997	Competitive environment, More flexible	Agility is about casting off of those old ways of doing things that are no longer appropriate- changing patterns of traditional operation. In a changing competitive environment, there is a need to develop organisations and facilities significantly more flexible and responsive than current existing ones
Devor 1997	New expression, Ability, Continuous change, Alliances, Core competence, Uncertainty,	Agile manufacturing is a new expression that is used to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, in technologies, in business enterprise. It requires to meet the changing market requirements by suitable alliances based on core-competencies, organising to mange change and uncertainty, and leveraging people and information
Bullinger 1999	Mobility, Changing market, Process, Re-determination, Self-organisation, Self-configuration	Agility means mobility in an organisation's behaviour towards the environment and can therefore be understood as an extensive answer to continually changing markets. Agile companies are in a process of constant re-determination, or self-organisation, self-configuration, and self-teaming
Yusuf, Sarhadi 1999	Exploration, Integration, Knowledge-rich environment, customer-driven product	Agility is the successful exploration of competitive bases (speed, flexibility, innovation pro-activity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment

It appears agile manufacturing is indeed a complex package (Yusuf, 1999). From the table it is evident that very different aspects of agility have been emphasized in the literature. However, by integrating the different views, taking account of manufacturing technologies, information technology, and environments, we propose a new comprehensive and synthetic description of *real* agile manufacturing. This overcomes a problem of incompleteness, or the partiality of the old, by attempting a synthesis of the key elements to demonstrate the importance of process.

> *Real Agile Manufacturing (RAM) is the strategic process of responding to the competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets. RAM takes multiple-winners (manufacturers, suppliers and customers) as an objective, integration (of resources, methods, technologies, departments or) as the means, with IT as an essential condition and core competence as the key.*

Figure 1 sythesises these points and demonstrates their relationships.

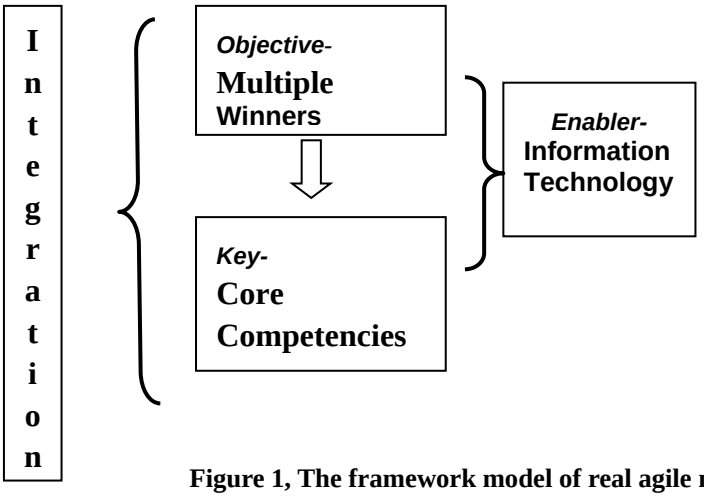


Figure 1, The framework model of real agile manufacturing

From our synthesis, the following five points appear to be the critical elements of RAM:

• Strategic processing ; Multiple-winners ; Integration ; Core competence and Information Technology (IT)

The following sections discuss these elements in detail.

Real agile manufacturing is a strategic process

Agile manufacturing is strategic processing (Goldman, 1994) in that it must be deeply incorporated in the organisation's development. However, different firms will vary in how they may strategically respond to the

changing business environment. One consequence of this is that may they use different levels of agility. From our synthesis of the elements of agility we can recognize that there are three distinctive levels of agility, which can be described as elemental, micro-agile and macro-agile. These levels of agility reflect the degree of incorporation the critical elements described above. But organisation forms can also be viewed at different levels, the individual level, the enterprise level and inter-enterprise level, Goldman and Nagel (1993,1995). But our interest lies with the most advanced form of agile manufacturing -real agile manufacturing- which crosses the boundaries of the organisation. It emphasises the building of core competence to enable the agile organisation to supply highly customized products. Figure 2 illustrates relationships across three organisational levels, emphasising the aspects of resource competence, to demonstrate the degree of agility.

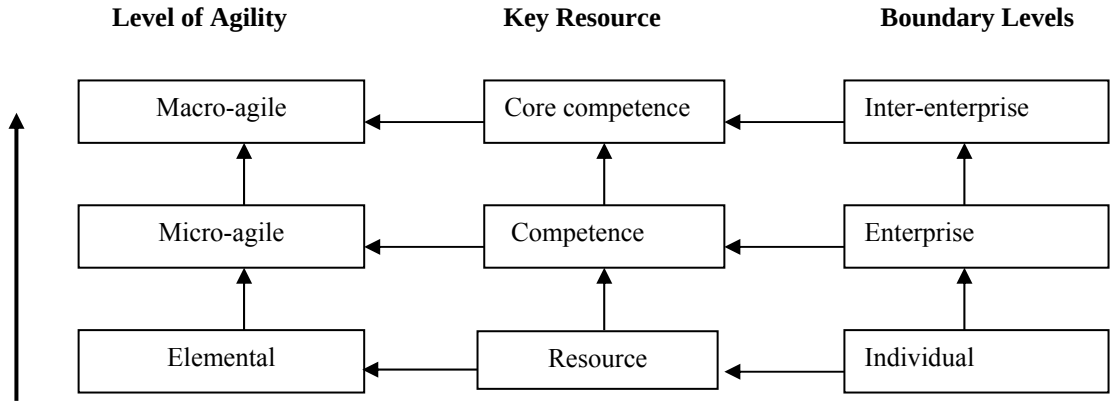


Figure 2 The Agility Hierarchy; relations of agility, competence and organisation level

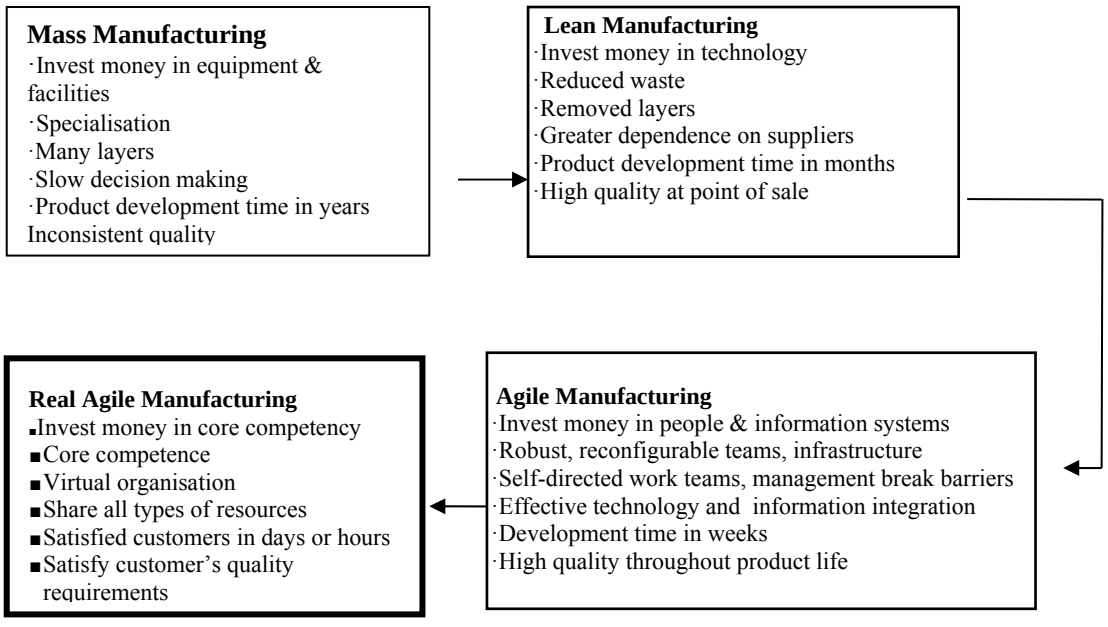
The alternative view of agile manufacturing, discussed earlier, is to see it as an incremental evolution from mass-production to real agile manufacturing. As we saw the need for agility arises from changing factors of technology, markets, management systems, knowledge, human philosophy and the social environment. McCarthy and Ridgeway (2000) argue that if the need for change arises from chaotic markets then it is likely, even common sense, that manufacturing organisations should be treated as complex *evolving* systems. However there are categorical differences between mass-production, lean production, agile manufacturing, and real agile manufacturing. Lean manufacturing, which emphasizes the efficient use of resources, is simply an enhancement of old mass-production methods. In contrast, new agile manufacturing systems break out of the mass-production mold and produce highly customized products. Booth and Hammer (1995) point out the fundamental differences:

- Lean production is regarded by many as simply an enhancement of mass production methods, whereas agility implies breaking out of the mass-production mould and producing much more highly customised products.

- In a product line context, agile manufacturing amounts to striving for economies of scope, rather than economies of scale—ideally serving ever-smaller niche markets, but without the high cost traditionally associated with customization.
- Agile manufacturing requires an encompassing strategic view, whereas lean production is typically associated only with the factory floor.
- Agile embodies such concepts as rapid formation of multi-company alliances or even virtual companies to introduce new products to the market.
- A lean company may be thought of as a very productive and cost efficient producer of goods or services.
- An agile company is primarily characterised as a very fast and efficient learning organisation .

Figure 3 shows the main elements of, and differences between mass, lean, agile, and real agility. It stresses the growing shift away from the concept of lean manufacturing towards the new management philosophy of agile production. Thusean manufacturing may be viewed as making more with less, whilst agile is a paradigm shift towards harvesting from core competencies.

Figure 3. Categorical differences in mass, lean, agile, and real agile manufacturing



The Objective of Multiple winners

Real agile manufacturing crosses organisation boundaries and may form virtual organisations. It is the integration of core competencies distributed among a number of carefully chosen, but existing

organisations with similar supply chains, to focus on speed-to-market, cost reduction and quality. This is because a single organisation may not be able to respond quickly to changing market requirements. As Sharp *et al* (1999:159) comment, "agility for an organisation is a paradox, in that an agile manufacturer has to be lean, flexible and able to respond quickly to changing situations; yet it recognised that no one company will have all the resources to meet every opportunity". Temporary alliances or partnerships based on the core competencies of the firms will help to improve the flexibility and responsiveness of organisations. However, co-ordination and integration become more complicated in this environment, so that an essential pre-condition of such partnership is mutual benefit. Thus we see collaborative advantage developing from such relationships. Accordingly, creating multiple winners is the objective of such agile partnerships .

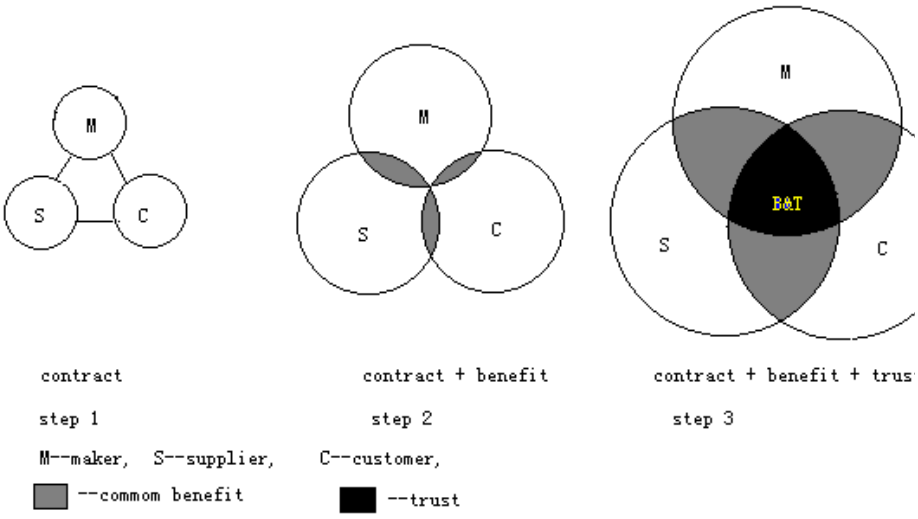


Figure 4 , Increasing collaboration to mutual advantage

Figure 4 shows relationships between a manufacturer, a supplier and the consumer in three stages, in effect the relationships within the value chain. The diagram illustrates how the common benefit, or value, can be increased within the relationship by increasing collaboration towards a shared purpose. Accordingly, the crucial issue becomes the search for common value in dealing with interface relationships. In the traditional independent organisation these relationships are internal, limited to employees of the organisation. Internal relationships can be improved through traditional managerial skills, such as cross-functional jobs or teams. But for virtual organisations, the relationships become externalised, and involve suppliers, customers, or other

manufacturers. Improving external relationships may become more complex, relying on the use of cross-organisation teams, information sharing, resources common using, and risk sharing. Each of these aspects needs be set up on the basis of trust. Traditionally, organisations have viewed themselves as independent entities in the chain and have separated themselves from their customers, suppliers, and other makers. As an example, consider figure 4, stage 1. As we move to stages 2 & 3 the partners in the virtual organisation form relationships and alliances with their external customers, suppliers (Lynch, 1989), and others. Increasingly, the focus of individuals and organisations is to work together to co-produce value, with their task becoming one of reconfiguring relationships to enable the creation of value in new forms (Normann and Ramirez, 1993). The parties involved need to have developed understanding and trust which will form a basis for a long-term relationship. The multiple-winners are created because of the collaborative advantage realised as a result of this co-operation and trust.

Integration as the mechanism

Integration is a focus within the contemporary research field (Yan and Jaing, 1999), but, as in the case of the term strategy, there appears to be little consensus about the precise meaning of integration. This may be a result of the variety of ways to integrate, or it may be simply be a matter of researchers still developing and expanding the concept of integration. The Oxford English Dictionary defines integration as the making up a whole by adding together or combining separate parts or elements; a making of a new whole or entirety. Some authors, for instance Burbridge *et al* (1987), focus their definition of integration on activities, which seems to correspond to the view of integration as the re-integration of differentiated organisational units. This view of integration deals with the integration of activities along activity chains, an issue made popular in "business process re-engineering (BPR)" (Hammer, 1990). Here integration is achieved by a combination of organisational and technological means as advocated by Hansen (1992). Integration can also be simply viewed as integrating internal aspects of a firm. Finally, there is the view of integration as a matter of co-ordination of centralised and decentralised control, i.e. integration between time horizons as advocated by Riis (1992) and Dam *et al* (1994). On this basis, Drejer (2000) proposed a three-dimensional model of ways to integrate product and technology development, integration of activities, integration of aspects, and the integration of time horizons. Nonetheless, it is clear that the objective of integration is to make the function of the combined system bigger (and better) than the sum of each part, as demonstrated in formula (1).

$$F_{whole} = \sum F_{parts} + \sum F_{new} \qquad (1)$$

F_{whole} --the whole function of the system,

$\sum F_{parts}$ --the sum of all parts of the function,

$\sum F_{new}$ --the new function which is created by the integration of all elements.

Above all, integration means synthesis, of pulling several parts together to create an organic whole that is optimised, efficient, and unified. The evolution of integration has gone through several phases. The initial objective was to build the activities integration into a single enterprise (see figure 5). This was followed by the integration of technology and managerial methods applications (see figure 6), and finally the integration of enterprises or inter-enterprises - the virtual organisation.

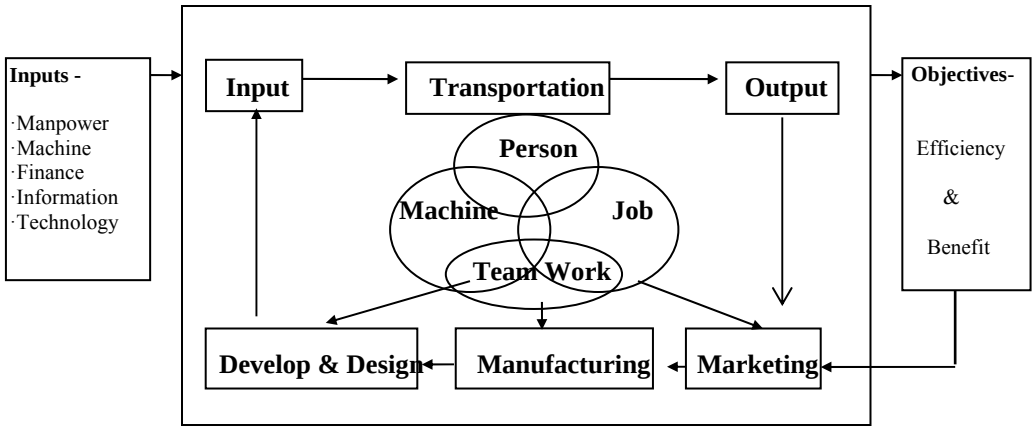


Fig. 5 The relationship of elements in the single enterprise system

In the wake of the developments in science and technology, managerial methodologies have gradually expanded their application fields from workshop level to enterprise levels, and from manufacturing to other, wider, circles. Classical management methods were mainly concerned with the production problems of the workshop or the factory. The aims were limited to raising the productivity in the production system. Modern management methods, in contrast, are concerned with the analysis, design, selection and activities of entire systems of the man-machine-environment. Consequently many new theories and methods such as JIT, MRP, TQC/TQM, Concurrent Engineering, BPR, QFD, Virtual Enterprise, Lean, Agile etc. were developed to satisfy the requirements of the enterprise. It is from this basis that effective manufacturing evolved as lean manufacturing and, eventually, agile manufacturing. The conceptual differences and the development of relationships between mass manufacturing, lean and agile are illustrated in Fig.6.

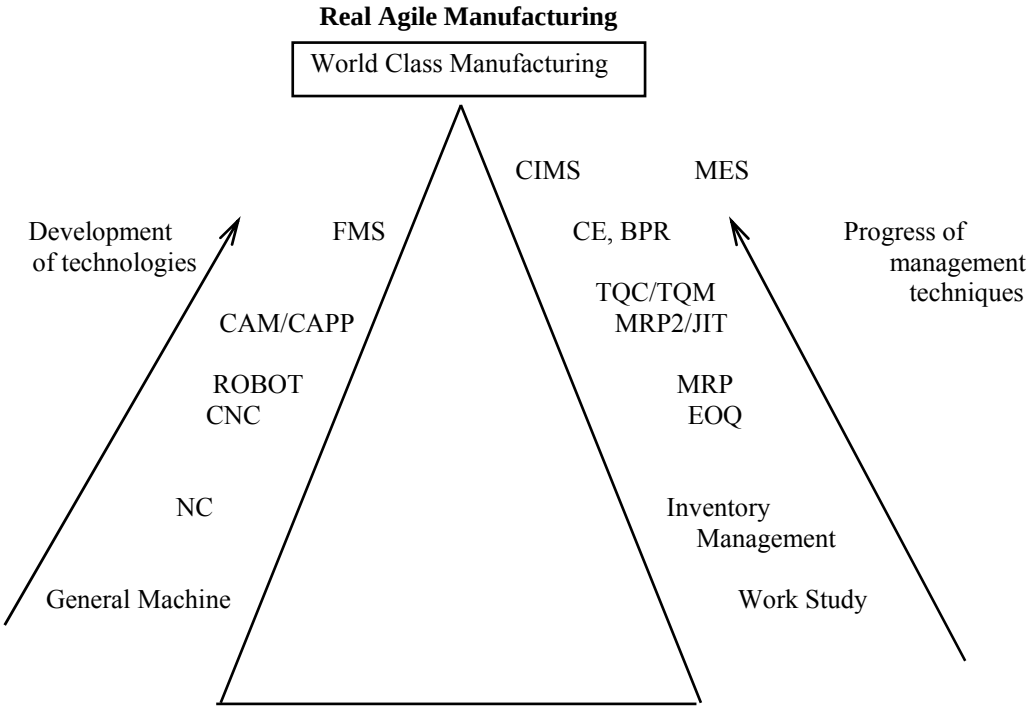


Fig. 6 The Evolution of Manufacturing Technology and Management Techniques

This diagram illustrates the convergence of the two evolutionary streams of manufacturing developments. Advances in technology (shown on the left hand side of the diagram) are associated with the progress in techniques (shown on the right hand side of the diagram). Hence we see the concurrent development and improvements of technology and technique. This demonstrates the evolutionary aspects of the developments. However the pinnacle of our diagrammatic evolution, RAM, combines these strands to provide something qualitatively different. Hence we argue that evolution becomes revolution.

Core competence is the key

The combination of the environmental changes discussed earlier led to the conclusion that the resources of single companies are no longer sufficient or adequate for each step of the value creation process. Thus the traditional value added chain is reshaped, so that companies now concentrate on their core competence (those aspects which they can do very well) while other functions or services are produced by their partners. Different sorts of core competencies are combined by a specific bundling of success-critical abilities. Prahald and Hamel

(1990) defined core competence as "the collective learning focused on developing and co-ordinating a diverse range of skills and capabilities. These are like the hidden roots of a tree, giving corporations their strength. Enterprises should use them to form core products, for use in a diverse range of business operations"(ibid., 1990:24).

Core competence, the highest level in the hierarchy, crosses the enterprises' boundaries. This level has the broadest scope where resources and capabilities are exploited and the greatest value can be realized. The corresponding organisational form is the flat virtual organisation. The term *virtual* in the virtual organisation is borrowed from computer terminology, where virtual memory can be defined as the use of secondary storage devices as an extension of the primary storage of the computer, thus giving the appearance of a larger main memory than actually exists. Virtual memory is basically a memory management tool for those computers with limited memory. Similarly, the virtual organisation is a system which expands and acquires more capabilities and power than the individual components inherently possess. There is a massive increase in the competitive advantage of those companies participating in a virtual organisation. However, because of the broader organisational scope of the virtual organisation there are difficulties in achieving such integration. Integrating core competencies requires collective organisational learning, deep involvement and the commitment to cross the enterprise boundary.

In recognising this notion of widening the scope of collective organisational learning we can also see that real agile manufacturing environment demands an agile workforce, that is one capable of shifting job functions and skills as the various situations warrant. Not only will the worker be familiar with the company's own product line, but in the partnering atmosphere of tomorrow's corporations the agile worker will be familiar with the partner's production situation. Agile companies must, in consequence, be committed to continuous workforce training and education. Therefore, continuous learning is the another attribute of agility. The relationships between organisation learning and core competencies are shown in Figure 7 and discussed below.

Elements of knowledge, learning and core competence

(1) Explicit knowledge learning means the ability to acquire knowledge from external sources. This learning cannot form an enterprise's core competence directly. However, when knowledge has been digested, absorbed and applied to production practice, it may form the enterprise's partial core competence, hence it represents a *potential* core competence.

(2) Procession learning (business learning) is "learning by doing". This learning is also crucial to the formation of potential core competence, because the experience and knowledge garnered from this process

extends the scope of core competence.

(3) Learning-by-R&D is the most important form. This is because innovation is the source of sustainable advantage and innovation cannot develop without R&D.

(4) Tacit knowledge learning broadly refers to mutual learning amongst members of the staff team, in particular in sharing experiential knowledge. To enable this form of learning, knowledge must be shared within a trusting environment and information integrated. Tacit learning can enlarge the scope of core competence.

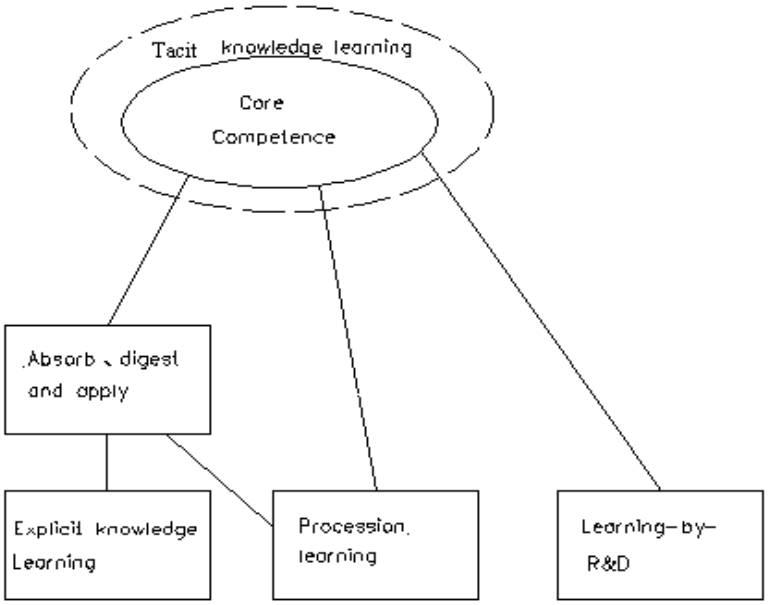


Figure 7 Relationships between learning and core competence

Prahalad and Hamel, (1990) and Senge (1998) consider that the short life of modern enterprises can be attributed to weaknesses in learning competence. They identify this as the so-called “Learning Barrier”, whose existence makes an enterprise unable to keep up with environmental change, hence hindering the organisation’s survival and development. The “learning barriers” are listed in table 2. The table also shows how these obstacles can be overcome through different forms of innovation. Accordingly developing learning competence requires specific activities during the innovation process.

Table 2 Learning barriers and solutions

Options	Learning barriers	Solutions	
Strategy	Unclear strategy	Strategy innovation	Implement strategic management
Thought	Lack of shared vision	Thought innovation	Build shared vision
	Lack of creative spirit		Personal mastery
	Illusion of experience		Improve mental models
	Lack of team learning		Carry out team leaning
	Part think		System thinking
Means	Outdated management means	Means innovation	Implement CIMS, MRP, ERP ,CAD ,CAM, etc
Organisation	Defects of structure and process	Structure and process innovation	Choose flat type structure Implement BPR

The broader scope of an agile manufacturing structure creates particular organisational difficulties. Developing a functional capability requires not only the co-operation of the individuals in one function, but achieving competencies requires the integration and co-ordination of several functions within the partnership. Moreover, exploiting core competencies depends on the corporation's ability to achieve integration, communication and co-operation between the different partners. It therefore becomes necessary to set up a cross-functional, and multi-functional team to coordinate the partners. Figure 8 provides an overview of the material, information and financial streams within the integrated organisation. Obviously the larger the number of the individuals involved, and the greater the variety of skills and backgrounds, the more difficult this task becomes.

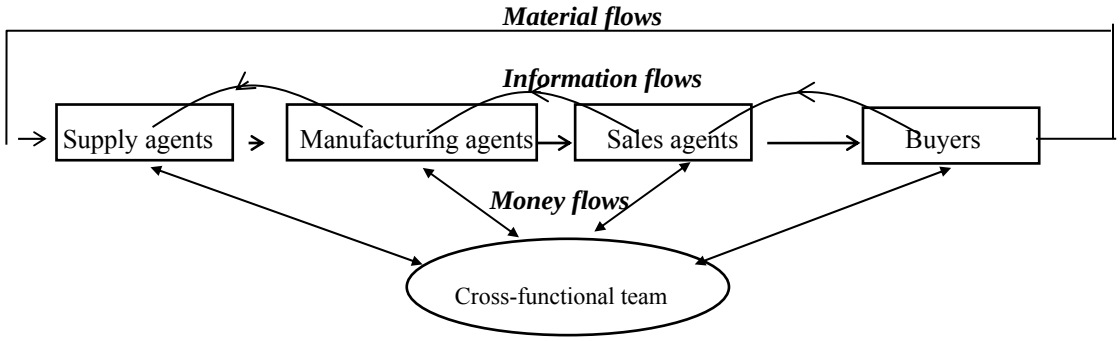


Fig. 8 Coordination Activities of the Cross-functional Team

IT (information technology) is the essential condition

The term IT is viewed in a broad sense, after Cooper and Zmud (1996), and as such it refers to any artifact whose underlying technological base is comprised of computer or communications hardware and

software. It is the enabling solution for the key issue of partnering in the virtual organisation, because it ensures that individuals and teams receive accurate information in a timely manner. Prompt, consistent provision of customer and performance data is necessary to implement effective responses within the value-added chain. It is therefore necessary to set up effective cross-functional information systems. Consequently to fully realize RAM, the roles and attributes of IT require specific attention.

Information technology plays a dominant role in integrating physically dispersed manufacturing firms and their partners. There are a number of enabling technologies which are critical to successfully accomplishing real agile manufacturing (RAM). These include robotics: automated guided vehicle systems (AGVS); numerically controlled machine tools (NC); computer-aided design (CAD) computer-aided manufacturing (CAM); rapid prototyping equipment; internet; world wide web (WWW), electronic data interchange (EDI); multimedia and electronic commerce. Virtual organisations which cross enterprise boundaries also require high level communication systems including Internet, Multimedia, CAD/CAM, MRP, ERP, EDI, EC, and virtual reality software (VRS) to eliminate non-value adding activities in the supply chain. This also helps to avoid human related errors in exchanging information and controlling various production and operations in RAM environments. In consequence, real agile manufacturing demands knowledge workers such as computer operators, design engineers, software engineers, systems analysts, corporate planners, and strategists.

IT has developed rapidly in the last decade. The extraordinary advances in telecommunications and computer technology, such as CAD/CAM, CMIS, MRP, ERP, EC, EDI, Virtual Reality Software (VRS), local data network (LAN) services, Internet/Intranet/Extranet, have make agility possible. EDI, for example, has had a significant role in reducing inventory levels in supply chains, corporate examples include Procter & Gamble, Nike, Boeing, GE, Intel and Dell. IT also enables of “chains”, so that concurrent engineering, and dynamic alliances can become real.

- **IT is a powerful tool for promoting innovation:** The key to the maintenance of enterprise core competence is the continued development of the core product. Thus the research and development section should embody the enterprise’s core competence. R&D is not only the source of an enterprise’s technological innovation, but is an essential element of continued competitive advantages in both products and the market. At present, enterprises with considerable competitive strength in marketing and production invariably rely on IT for the design and development of products. Computer aided design (CAD) and computer integrated manufacturing system (CIMS) are two typical examples. These advanced methods of design and development

greatly reduce the development cycle time of new products, and make it possible to manufacture products with different specifications according the demands of customers and the market. Additionally, IT contributes to the rapid formation of customised products, so that rival enterprises find imitation more difficult.

- **IT is the basis of an enterprise's information resources:** As the saying goes, the ability to hear well may lead to a thorough grasp of the situation. Nowadays, with fierce market competition, information has become an important strategic resource, but it is also the foundation on which an enterprise builds and maintains its core competence. Therefore, the effective utilisation of IT in the management and processing of information flows to provide accurate and timely information for operations and decision making, is one of the major yardsticks of an enterprise's competitiveness. IT has also creates advantage in an enterprise's procedural improvements and organisational innovation.

- **IT is the bridge between partners.** Two of the principal representations of an enterprise's core competence is the market occupation rate of the enterprise's products and that their reputation among customers should exceed those of its rivals. IT has become an effective competitive tool when used to establish a market feedback mechanism and to maintain close contact with consumers. Many prestigious enterprises provide special services such as product introduction, ordering, customer training. Some even respond to questions through their own computer network or by the internet. These organisations not only create a favorable image of their enterprise but they also establish a close partnership with their customers.

- **IT is a platform for knowledge management and the learning-oriented organisation.** The 21st century is an era of knowledge innovation. The cultivation of enterprise core competence consists, above all, in the management of knowledge. Thus knowledge must be shared within the entire enterprise to become the foundation of sustainable growth. At present, many knowledge-oriented organisations apply IT to the collecting, sorting and sifting of the implicit knowledge for employees to share, study and utilise. Not only can knowledge management systems facilitate the management of existing knowledge capital, but can also improve working conditions to facilitate the exchange, creation and accumulation of new knowledge. Only in this way can knowledge create value, so the essence of knowledge management is the efficient utilisation of knowledge to reinforce an enterprise's competitiveness.

8. Conclusion

With the rapid changes taking place in the global market, it becomes clear that manufacturing enterprises working on a RAM base should become leaders, but to effect this new managerial system, new

approaches to technology and new ideas need to be continuously developed. This paper synthesizes some of the research work done on the agile manufacturing to develop a framework for the development of RAM. Manufacturing has evolved from mass manufacturing, lean manufacturing, agile manufacturing to the new revolutionary form- real agile manufacturing. We have argued that to realise RAM, companies must create multiple-winners (manufacturers, suppliers, customers) as their objective, integration (resources, methods, technologies, departments or organisations) as the means, IT as the essential condition and with core competence as the key. However, the range of the topic requires more research, particularly feasibility studies from the perspective of establishing virtual organisations and how they realize RAM. We suggest that the following agenda represents the major issues that should be considered by researchers and practitioners when studying and developing RAM:

- A methodology for evaluating potential partners for RAM based on core competencies and market forces needs to be developed. In particular, qualitative and quantitative criteria for selecting partners of real agile enterprise should be identified with the help of suitable conceptual and empirical research.

- The managerial models and organisational characteristics of real agile manufacturing need to be continuously monitored for effectiveness.

- As manufacturing systems evolve from mass, lean, agile, to real agile, the importance of social capital between organisations appears to become more significant. We need therefore to understand the role and formation of social capital in RAM. How can we build and develop social capital in the virtual organisation?

- In real agile manufacturing, supply chain links are often temporary and hence flexible. Therefore, there is need to develop new supply models, and to create techniques for measuring performance and evaluating risk in the new agile systems.

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