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Agile manufacturing: The drivers, concepts and attributes

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Abstract

Agile manufacturing, a recently popularised concept, has been advocated as the 21st century manufacturing paradigm. It is seen as the winning strategy to be adopted by manufacturers bracing themselves for dramatic performance enhancements to become national and international leaders in an increasingly competitive market of fast changing customer requirements. This paper identifies the drivers of agility and discusses the portfolio of competitive advantages that have emerged over time as a result of the changing requirements of manufacturing. The need to achieve the competitive advantages of manufacturing in synergy and without trade-offs is fundamental to the agile paradigm. To further the understanding of agility, this paper reviews the meaning of agility from different perspectives and suggests a comprehensive definition which can be adopted as a working definition by practitioners. Four underlining concepts of agility has emerged from the working definition and the paper presents a representation of these concepts and their interactions. Finally, the paper highlights some of the key enablers of agility and identifies potential future research directions.

Keywords: Agility; Drivers; Concepts; Attributes; Enablers

1. Introduction

There is an increasing recognition that agile manufacturing is a necessary condition for competitiveness. The original concept was popularised in 1991 by a group of scholars at Iaccoca Institute of Lehigh University in USA, and it is gaining currency among practitioners and academics alike, as the next battle ground for global competition in the face of shrinking conventional markets and fading national barriers. The concept owes a lot to advances in communication technology and previous paradigms of manufacturing, yet it is more than a hybrid construct of technology and any previous method of production. It advocates a holistic, rather than a sub-optimal, approach to manufacturing. The concept is at the moment a vision and currently being refined to further its understanding.

There is yet no company that is truly agile in the sense of having acquired all the essential characteristics identified in the growing body of literature on agile manufacturing. There are important issues and questions that need to be addressed to understand how agile manufacturing might be achieved with clarity of purpose, focus and goals.

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This paper presents the genesis of the agile manufacturing concept, and examines the manufacturing imperatives and potential competitive advantages that are the driving forces behind agility. The paper also reviews definitions of agile manufacturing and proposes a comprehensive definition embracing the competitive foundations of agility and the key concepts of agile manufacturing. In so doing, the paper attempts to address some of the basic requirements for achieving agility. Finally, the paper presents some of the problems to contend with if agility is to be of long-term benefits for prospective agile companies.

2. The 21st century manufacturing paradigm

Agility, as a concept in manufacturing, was coined by a group of researchers at Iaccoca Institute, Lehigh University, in 1991 [1] to describe the practices observed and considered as important aspects of manufacturing during their investigation. The group involved many of the senior executives of US companies and the study culminated into a two volume report conveying an industry-led vision for a possible profound shift in manufacturing paradigm.

The report was, mainly, on how USA could regain its pre-eminence in manufacturing. It described initiatives in USA, Western Europe and Japan aimed at creating an industrial climate that will ensure competitiveness in the emerging global manufacturing order. The agile manufacturing paradigm was recommended as holding the potential, if adopted, for the USA to resume a leading role in manufacturing. Included in the report is a view of agile manufacturing enterprise, components, infrastructure and operating mechanisms. It also identified competitive foundation, characteristics, elements and enabling subsystems of agility. The report was a pioneering work and was well received by academics, practitioners and government officials.

However, Burgess [2] argues that agility was yet ill-defined and more work needed to be done to refine the concept. For example, the concept of agility as expounded in the report lacked solid grounding in management theory. The work also did not take account of the differences between organisations, for example, incorporate culture or philosophy.

3. The drivers of agility

The main driving force behind agility is change. Manufacturing has tended toward gradual change and adjustment in response to the prevailing market circumstances. In this section the changing manufacturing requirements that have culminated in a broad spectrum of competitive criteria will be briefly reviewed. Intimate understanding of the requirements of modern manufacturing is important in order to set a proper agenda for strategy implementation. The issues discussed below relate to automation and price/cost consideration, widening customer choice and expectation, competitive priorities, integration and proactivity and achieving manufacturing requirements in synergy.

3.1. Automation and price/cost consideration

As implied above, the pressure on manufacturing has always been dictated by the market. The post World War II period was characterised by relatively high demand and an inability to supply. The increase in demand after the war created extended backlogs of customer orders which served as firm orders on which material planning could be based [3]. Quality and speed were not of considerable significance as consumers were scrambling for the available products on offer. Price was the dominant factor that determined customers preferences [4]. This encouraged massive automation of production processes with resultant mass production of goods. The single most important objective of manufacturing was mass production of goods at lower prices. The automation was rigid and flexibility was constrained.

3.2. Widening customer choice and expectation

The changing market and shift in customer preferences in favour of quality gave birth to the 1980s'

quality crusade. This led to aggressive and unprecedented focus on quality while maintaining competitive price. Increasing customer expectation in the form of strong taste for quality helped intensify the attention devoted to product quality initiatives. Pursuit of quality by manufacturers was also complemented by the army of researchers and consultants who popularised quality related concepts such as total quality management (TQM), statistical process control (SPC), and quality function deployment (QFD).

3.3. Competing priorities

Several criteria for competitiveness have emerged within the first half of the 1990s. These competitive priorities include responsiveness, new product introduction, delivery, flexibility, quality, concern for the environment and international competitiveness. The market place has turned into "battlefields". An archetypal scramble for market was demonstrated by stiff competition between Yamaha and Honda for Japanese market share in the 1980s. [5].

3.4. Integration and proactivity

The long established paradigm of manufacturing management is largely reactive. In a highly competitive market manufacturers must be able to act proactively. A proactive manufacturer will integrate with customers and help identify their problems and requirements and also acquire capabilities just ahead of need [6,7]. In this way, proactivity offers strategic advantage for competing in the turbulence of the global market. The strategic capabilities afforded by proactivity is strongly dependent upon the integration and co-ordination in the enterprise that the strategic manufacturing systems must be efficiently integrated and coordinated [7].

3.5. Achieving manufacturing requirements in synergy

From the foregoing discussion it is apparent that one competitive thrust cannot win the battle for any company. The importance of speed cannot be overstated. The flexibility of production machinery as well as employees and the organisation are required for a corporate-wide flexible strategy. Mair [8] espouses the concept of "flexifactory" and argues that it is a vehicle for transcending micro-flexibility and realising an overall flexible corporate strategy. Though quality is now an order qualifier rather than an order winner, it remains important. To remain competitive, manufacturers are required to produce products at lower cost, high quality and with decreasing lead time. In addition, they must remain proactive and innovative.

A successful company must therefore acquire the capability to achieve and explore the competitive advantage in synergy. Integration both of a technical and social nature, of technology, machinery, functions, strategies, people and management, lies at the foundation of these competitive capabilities. The competitive advantage will have to be achieved using the best resources available to an organisation or a group of organisations.

A common theme that runs through the scenario depicted above is change. Successful organisations must be able to foresee, adapt and respond to change using tactical initiatives to achieve strategic objectives. It is important to engage in creatively initiating change and to become proficient in it. Survivors of the current competitive storm are those organisations that use their proficiency in change as a lever to outperform their competitors [9].

4. What is agile manufacturing?

Since the publication of the Iacocca report, many publications on agility have appeared, in book forms [10,11], trade magazines [12–15] and academic journals [2,5,16,17]. As a mark of the newness of the concept, every publication attempts to define and explain agility. Agile manufacturing has been defined with respect to the agile enterprise, products, workforce, capabilities and the environment that gives impetus to the development of agile paradigm. The main points of the definition of various authors may be summarised as follow:

- High quality and highly customised products [9,11,18,19].
- Products and services with high information and value-adding content [9,10].
- Mobilisation of core competencies [9,11].
- Responsiveness to social and environmental issues [9–11].
- Synthesis of diverse technologies [2,11].
- Response to change and uncertainty [9,10,12].
- Intra-enterprise and inter-enterprise integration [20,11,21,22].

4.1. The scope of agility

Youssef [23] argues that agility should not be equated just with the speed of doing things, for it goes beyond speed and it requires massive structural and infrastructural changes. Equating agile manufacturing with speed of response or flexibility is a narrow understanding of what constitutes agility. Although agility incorporates speed and flexibility, according to Kidd [11], it is much more than that. 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, MRPII, BPR, Employee Empowerment, and OPT. This view is corroborated by Goldman and Nagel [9]. They contended that agile manufacturing "assimilates the full range of flexible production technologies, along with the lessons learned from total quality management, 'just-in-time' production and 'lean' production".

4.2. Agility defined in terms of outcomes

Agility has been defined, in terms of outcomes, as "dynamic, context specific, aggressively change embracing and growth oriented … succeeding … winning profits, market share and customers" [10]. In other words, agility is the ability of a business to grow in a competitive market of continuous and unanticipated change, to respond quickly to rapidly changing markets driven by customer-based valuing of products and services [5,24]. By focusing on the output, Gehani [25] asserted that "an agile organisation can quickly satisfy customer orders; can introduce new products frequently in a timely manner; and can even get in and out of its strategic alliances speedily". However, a further insights into agility could be gained by looking at the specific and operational issues.

4.3. Agility in terms of operationalisation

According to Kidd [11], to operationalise agility, it can be defined as "the synthesis of a number of enterprises that each have some core skills or competencies which they bring to a joint venturing operation … " thus enabling the cooperative enterprises to adapt and respond quickly to changing customer requirements. A fairly specific and succinct definition of agility has been proposed by Kumar and Motwani [16]: " … ability to accelerate the activities on critical path and … time-based competitiveness". In other words agile organisations are able to compete on the basis of time-compression.

4.4. Comprehensive definition of agility

The proponents of agility at Iaccoca Institute of Lehigh University (USA) have defined it as [23]: " … 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)". This definition embraces the concepts reflected in the model of agile manufacturing proposed by Youssef [21]. The model defined a framework for agility through representation of the interactions between the manufacturer, customers, suppliers and the basis for competition in the agile paradigm.

Obviously, different facets of agility have been emphasised by various authors and this has lead to

varied views reflected in the literature. These definitions should be considered simultaneously in order to gain a better understanding of what constitute agility. Taking all the definitions together, it appears agile manufacturing is indeed a complex package, the content of which has not yet penetrated the collective consciousness of researchers and practitioners alike.

In the light of the growing number of literature on agility, and the breadth of interest in it, a more comprehensive definition is being suggested in this paper.

"Agility is the successful exploration of competitive bases (speed, flexibility, innovation proactivity, 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".

This definition shares some properties with the earlier definitions but it is different in four respects:

- Firstly, it is comprehensive in that it defines agility in terms of input, operationalisation and output. It therefore embodies, and properly expresses, the concept of agility as a system. This is a systematic approach that will enable practitioners to distinguish between the required input, the operating mechanism and tools, and the desired output.
- Secondly, the competitive foundations of agile manufacturing are made explicitly clear. The bases for competition include: speed, flexibility, innovation, proactivity, quality and profitability. This portfolio of competitive thrusts have been recognised as the sine qua non of manufacturing which must be achieved in synergy [22,26].
- Thirdly, there are three levels of agility implicit in the definition. That is, agility for the individual (and other resources), enterprise and inter-enterprise. Goldman et al. [10] have already highlighted agility for individuals and enterprise. A third level of agility for inter-enterprise is being suggested in this paper. Fig. 1 presents the hierarchy of agility and the corresponding characterisation, viz. elemental agility, micro-agility and macro-agility. The figure suggests that a truly agile organisation focuses on individual resources (people, machinery and management), and the functions that make up the enterprise to achieve the best possible output. It is the harmonisation of these aspects of the organisation that leads to agility rather than their respective optimisation. Further to achieve the higher level of agility the core competencies of prospective partners must be brought into joint venturing to maximise the gains of cooperation.
- Finally, the definition takes cognisance of the four main concepts of agility. It is increasingly being recognised that there are four key concepts for agile competition. These concepts include competition based on core competence management, virtual enterprise formation, capability for re-configuration and knowledge-driven enterprise. The interactions of these four concepts are illustrated in Fig. 2. These concepts are discussed in detail in the following section.

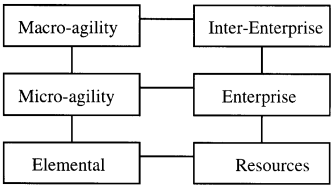

Fig. 1. Hierarchy of agility.

5. The core concepts of agile manufacturing

The model presented in Fig. 2 includes the following core concepts of agile manufacturing.

5.1. Core competence management

Core competence may be associated with the corporation's workforce and product and identified at two different but related levels, the individual and the firm. The core competencies of individual include their skills, knowledge, attitude and expertise [11]. Through investment in training and education the core competencies of individuals within the enterprise can be upgraded and re-focused to take advantage of current and potential

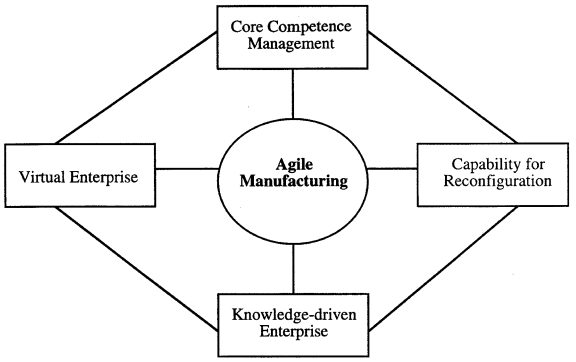

Fig. 2. The core concepts of agility.

trends in customer requirements. Kidd [11] and Goldman et al. [10] have described people as the critical resource of an organisation. Prahalad and Hamel [27] stated that people are the competence carriers.

The work of Prahalad and Hamel [27] on core competence is uniquely outstanding. According to them core competence derives from corporate-wide learning process, integration of diverse skills and streams of technologies, work organisation, creation and delivery of value and capability for inter-organisational cooperation. For core competence to be of strategic importance and bring long-term benefits to the corporation it must meet three conditions. Core competence should provide capability for multi-venturing and access to a wide spectrum of markets. It should also strongly enrich customer valuing of end products and be difficult for competitors to copy. Creating and building core competencies is, however, not an easy task. Management, who have the sole responsibility for core skills and knowledge acquisition, must begin by listing the company's main capabilities and identifying the missing links. The missing links can be "insourced" or acquired through alliance. Cooperation is very important here even with competitors. This implies that in agile paradigm competition and cooperation are mutually compatible.

Cooperation among enterprises provides the platform for rapid response to the level of demand which would, otherwise, be impossible for individual organisations to achieve. Requirements for complex new products can easily be met through an interactive network, "allowing physically dispersed and organisationally segregated personnel from the same company to work collaboratively with one another and with personnel from other companies" [9]. This is often referred to as virtual corporation. In a virtual corporation, competence carriers are transparently available to all business units. Talented personnel can easily be redeployed as the windows of opportunities open and close. Agile organisations, therefore, are apt to increase the stock and velocity of circulation of their talents [27].

5.2. *Virtual enterprise*

The virtual enterprise is different from the traditional corporate alliance. Fig. 3 presents three

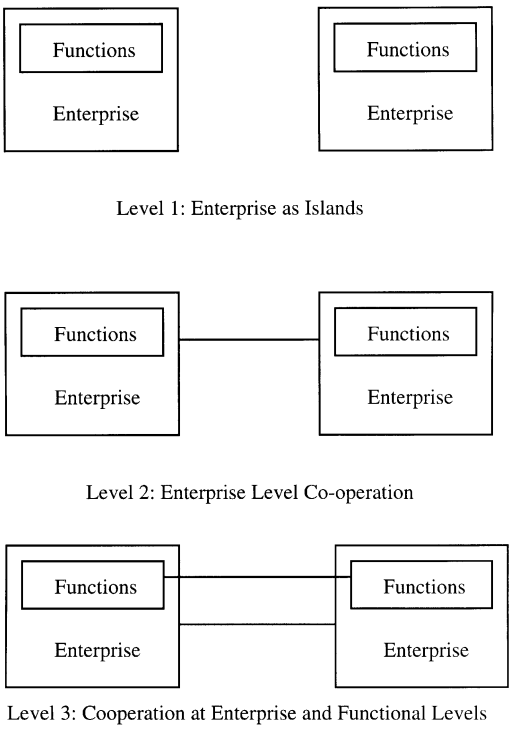

Fig. 3. Partnership development model.

levels of cooperation among enterprises culminating in virtual partnership. The first stage represents enterprises that have operated as isolated islands. Interactions between companies at the corporate level with little or no liaison at the operational levels are depicted in stage two. For example companies may enter into purchasing agreement and exploit EDI to facilitate cooperation but management make the decision without involving functional staff. In stage three agile organisations form virtual enterprises and cooperate both at the corporate and operational levels. Agile teams work across the company partners. This is the climax of cooperative venturing. It allows resources and diverse skills which are spread across disparate organisations to be harnessed and coordinated for manufacturing products, simple or complex, very quickly in accordance with customer specifications. Customers can become part of the web of firms a context within which QFD becomes more meaningful as a facilitator for translating customer requirements into end products. Although the technology for achieving the third stage scenario may be available, the key business processes are poorly understood and ill-defined. Accordingly, Goldman and Nagel [4] suggested that "techniques need to be developed for managing companies that promote workforce initiative at the operational level, as well as performance measures for self-directed, inter-enterprise, project teams".

There are two possible approaches for operationalising the virtual enterprise. A big corporation can re-organise its business units, and re-focus on core competencies, to operate as a virtual enterprise. Such a corporation will have no need for giving away its expertise. The lack of focus on core competence, for example, was a key factor in Chrysler giving away their engine design responsibility in the late 1980s [27]. The other possible approach is for small companies to come together and deliver the quality, scope and scale of products and services which they would not have been able to provide individually. There is a great potential, therefore, for exploitation of the agile principles and practices by SMEs through rapid partnership formation. However, the right mindset among employees, the necessary business practices required, processes, as well as the methods and tools, are not yet sufficiently developed in the UK. For example, a simple question such as "How do we go about becoming agile?" cannot be answered with clarity as there is no available guide and refined methodology.

5.3. Capability for re-configuration

Agile enterprises can easily make a significant shift in focus, diversify, configure and re-align their business to serve a particular purpose rapidly as the windows of opportunities open. In addition, they are capable of pre-empting competition. The key to that, Prahalad and Hamel [27] argue, is to develop a strategic architecture featuring a corporate wide map of core skills. This type of organisation is well positioned to take advantage of speed, by getting to the market before competitors with new products, and proactivity, by providing the products that will be required by customers just before the need arises. Operational reconfiguration is necessary to capitalise on the strategic architecture. Management must invest in technologies that confer operational flexibility at the plant level. However, Goldman and Nagel [9] have cautioned against placing excessive premium on technology "however dazzling their performance" and concluded that "the notion that new technologies confer competitive advantage through some intrinsic properties that they possess is a fundamental misconception".

5.4. Knowledge-driven enterprise

Kidd [11] has broadly defined knowledge, with respect to manufacturing, to include experiences of people in the organisation, company reports, case histories, databases and other repositories. Organisations which intend to become agile should include the development of a well trained and motivated workforce, with the right set of skills, expertise and knowledge, as an essential element of their strategies. Such organisations are driven by knowledge and information possessed by and available to the work force. This epitomises the notion that "knowledge is power".

The concept of knowledge-driven enterprises derives from increasing recognition of knowledge and information as the main differentiators of successful business. The success of any organisation ultimately depends upon its ability to convert the collective knowledge and skills of its most critical resource – people – into solution products. The use and manipulation of information, as a key competitive instrument has also revolutionised the way that we think about manufacturing and how we operate it. The ability to control the new product introduction process from the conceptualisation and design stages through manufacturing to shipment and product support requires the exploitation of a knowledge-rich work force and sophisticated information technology in most industrial sectors. Agility introduces a new dimension to customer support to include the provision of access to enhanced functionality originally embedded in the product. In essence the customer is getting an upgraded product at a lower cost than would otherwise have been the case. The manufacturer also saves the time for production of an entirely new product to account for the new customer requirements. In a way, this is also environmentally friendly as it eliminates the need for a new product with enhanced performance.

6. Achieving attributes of agility

Burgess [2] proffered IT-enabled processes for achieving agility and identified five stages depending on the nature of the manufacturing outcomes. These stages include localised exploitation, internal integration, business process redesign, business network redesign and business scope redefinition. In the opinion of Burgess, these stages result in islands of automation, computer-integrated manufacture, agile manufacturing enterprise, virtual agile enterprise and redefined virtual agile enterprise, respectively. Organisation must evolve through any of the processes identified to achieve the desired outcome of manufacturing. Although Burgess did not provide explicit comment on the vision of the redefined virtual enterprise with its redefined business scope, suffice it to state that such an enterprise will be infinitely flexible in its tactical and strategic concerns.

Gehani [5] suggested six actions required for the implementation of an agility-based strategy: Cross-functional team sharing, empowerment for front-line decision making, modular integration of available technologies, delayed design specification, product succession planning and enterprise-wide integration of learning. According to Gehani [5], by "early involvement of marketers in product concept definition, and involvement of manufacturers in engineering of the processes for producing the product, many potential downstream problems are pre-empted and prevented at an early stage". Kumar and Motwani [16], who are of a similar opinion regarding concurrent engineering, stated that "savings in development time accrue from the fact that the backtracking needed to solve problems when these activities are performed in chronological sequence is reduced or completely removed". Such cross-functional teams will need to be supported by a concurrent information structure and infrastructure. The concurrent paradigm, as opposed to the sequential paradigm, has been examined by Pant et al. [28]. Their model of this parallel paradigm was validated through case studies and they demonstrated that significant gains in speed can be achieved through parallel information processing and concurrent execution of functions.

Employee empowerment is a well re-hearsed concept in manufacturing strategies and is a critical part of TQM. Empowerment enables employees to take decisions and provide remedial actions quickly. Such speedy responses will have a significant impact on the rate of order fulfilment. Similarly, modularity will enable the organisation to meet the customer's specifications by modifying quickly parts of the product. Delayed design specification gives more room for late-minute changes. The product planning and definition stages can take a long time and final production need only be started after the customer is satisfied with the specification.

An agile organisation must develop a strategic plan to launch new products in succession. Launching a single product hastily without a follow-up could be counter-productive. Youssef [21] cautioned against speed-to-market in spite of its virtues and wrote that "using speed as a strategy must be planned carefully, for otherwise speed can be

fatal". Enterprise-wide integration of functions can lead to the significant achievement of a broad spectrum of competitive advantages. For example, Yusuf [22] when investigating enterprise-wide integration of functions and technologies that were traditionally isolated, such as computer-aided design (CAD), computer-aided manufacturing (CAM), manufacturing resource planning (MRPII) and distribution resource planning (DRP), found that integrated organisations are better than their less integrated counterparts. This superiority was true for a range of competitive advantages including responsiveness, customer service, new product introduction and quality improvement. An integrated learning process occurs when managers focus on their companies' "longitudinal histories" to avoid previous mistakes.

Collectively these literature provide insights to what constitutes agile practices and attributes of an agile organisation. The suggested attributes of agility are summarised in Table 1. The table presents 32 attributes, in 10 decision domains, of an agile manufacturing enterprise. The pathways and obstacles to achieving these attributes are important issues for consideration if progress is to be achieved in moving towards agility. Also important is the metrics for the processes that are required for achieving agility. These requirements are represented in a conceptual framework in Fig. 4. The framework integrates a set of practices (attributes), metrics and pathways or obstacles to achieving agility.

Table 1
The attributes of an agile organisation

Decision domain	Related attributes
Integration	Concurrent execution of activities
	Enterprise integration
	Information accessible to employees
Competence	Multi-venturing capabilities
	Developed business practice difficult to copy
Team building	Empowered individuals working in teams
	Cross functional teams
	Teams across company borders
	Decentralised decision making
Technology	Technology awareness
	Leadership in the use of current technology
	Skill and knowledge enhancing technologies
	Flexible production technology
Quality	Quality over product life
	Products with substantial value-addition
	First-time right design
	Short development cycle times
Change	Continuous improvement
	Culture of change
Partnership	Rapid partnership formation
	Strategic relationship with customers
	Close relationship with suppliers
	Trust-based relationship with customers/suppliers
Market	New product introduction
	Customer-driven innovations
	Customer satisfaction
	Response to changing market requirements
Education	Learning organisation
	Multi-skilled and flexible people
	Workforce skill upgrade
	Continuous training and development
Welfare	Employee satisfaction

7. Further work

More work needs to be done on the core concepts of agility discussed in this paper. For example, the key business processes for organising and optimising operational level inter-enterprise cooperation is not well understood. Employees that have hitherto worked within, and maintained allegiance to, their sections in a typical departmentalised organisation, will be required to work in a transparent virtual organisation without functional barriers. This will require a tremendous change in attitude and approach to work. Each employee will be required to view and understand her work in terms of the whole rather than the part. For example, an aircraft wing designer must perceive herself as an aircraft manufacturer and place her work in the context of aircraft manufacture and sales. Another important issue relates to nurturing core competence and its deployment. For example, when organisations transfer their core competencies to form virtual enterprises what happens to their competencies that are not core or what happens to the gap created by "virtual" absence of the

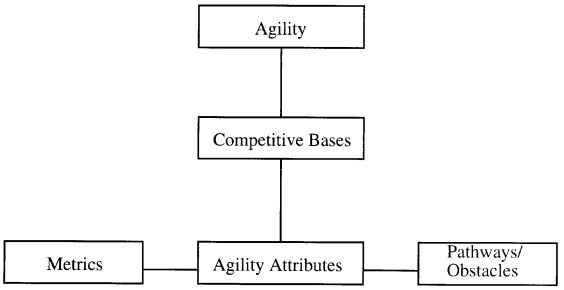

Fig. 4. A framework for achieving agility.

core competence? These, and may other, questions need to be properly addressed if agile manufacturing is to be practised to the full.

QFD may offer a solution to these questions. It can be used to assess and rank the capabilities of an organisation vis-à-vis their competitors. These capabilities can then be matched to customer requirements in order to determine the competitiveness of the organisation. A similar approach can be adopted, using QFD to evaluate core competence of an organisation. In addition, a strategic mission statement of an organisation can be used to assess the requirements for future core competence using QFD. Succinctly, the application of QFD in identifying, creating and nurturing core competencies of organisations needs to be investigated.

The enablers of agility need further exploration to find out best examples of each and of the underlining practices that help achieve, sustain and maintain each one over a long period of time. Along with this is the need to explore how to integrate the gamut of such best practices in a single company. To identify the best practices however will require extensive investigations and comparative analyses of cases.

8. Conclusions

Agile manufacturing may be new as a concept but aspects of the practices embodied in agility are already in place separately. To extend understanding of agility there is the need to develop a working understanding and models of agile manufacturing. Such models may not be radically different from those of the existing manufacturing paradigms, since agility does not negate any of the earlier paradigms. What is required is a methodology for synthesising the existing models to aid their application.

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