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Emergence of global manufacturing virtual networks and establishment of new manufacturing infrastructure for faster innovation and firm growth

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This paper summarises preliminary research findings from fieldwork conducted over the last three years. It introduces some typical case studies in electronics, bio-technology, home electronic appliances, and leisure apparel industrial sectors studied in order to demonstrate the background to and driving forces of manufacturing's transformation towards the global manufacturing virtual network (GMVN). It suggests that the GMVN—a new manufacturing architecture—has many distinguishing characteristics and is a promising example of the potential manufacturing configurations which could be based on a collaborative infrastructure and supporting ICT in order to address dramatic forthcoming changes in an increasingly fragmented market environment. The GMVN provides a new platform that engages developing countries' manufacturing firms to play complementary roles and to be integrated into a global supply chain.

Keywords: Global manufacturing virtual network (GMVN); Networked organization; Contractual manufacturing service (CMS)

1. Introduction

One of the most identifiable trends in the fundamental changes that are currently transforming the manufacturing industry is that the traditional, vertically-integrated value-chain is being replaced by collaborations between specialised independent companies. While some companies are pursuing subcontracting to allow them to concentrate on their customers and core competences, others are building their business by focusing on these same outsourced tasks. Original equipment manufacturers (OEMs) are evolving into total solution providers, whilst contract electronics manufacturers (CEMs) are developing into electronics manufacturing service (EMS) providers. Collaborations between these two groups are resulting in global manufacturing virtual networks (GMVNs) that profoundly challenge existing business models and traditional concepts such as 'manufacturing', 'service industry', 'supply chain', and even 'firm' or 'enterprise'.

There are many unresolved questions in this new manufacturing transformation. This paper seeks to explore the new phenomenon of inter-firm collaborations in the electronics industry and to understand in more detail the nature of virtual manufacturing networks and the issues that they raise. It proposes a conceptual framework for the GMVN, as a new platform for configuring manufacturing resources, and a common language that is relevant to different disciplines. It suggests that the GMVN represents a new type of manufacturing system which has distinguishing capabilities based on internet communication infrastructure and new models of collaboration. The GMVN is also recognised as a foundation of the future e-manufacturing.

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2. Research on GMN, ISA and VO

In an era of globalisation, the nature and intensity of competition has been changed dramatically. Three interrelated concepts have been developed by researchers to describe the way companies are responding, or should respond, to this change. They are the global manufacturing network (GMN), the international strategic alliance (ISA) and the virtual organisation (VO).

GMN research has its roots in the disciplines of production and operations management and manufacturing engineering. It seeks to extend traditional manufacturing system boundaries from the factory towards globally dispersed and co-ordinated factory networks. However, this research is still mainly focused within a single multinational corporation (Flaherty 1986, 1996, Ferdows 1989, 1997, Shi and Gregory 1997, 1998). It is clear that the appropriate co-ordination of international manufacturing networks based on the strategic business unit (SBU) or product family can help multinational corporations compete globally. However, the weakness of this research is not only that it focuses on single corporations (or even smaller SBUs), but also that it does not address inter-firm collaboration or the impact of emerging technology on manufacturing systems.

The ISA, which does address inter-firm collaboration, has been advocated as a 'logical and timely response to intense and rapid changes in economic activity, technology, and globalisation' (Doz and Hamel 1998). It is implicit in this view that in the new competitive environment no company can compete in either domestic or global markets without partners. The ISA between manufacturing companies to form an international manufacturing network has become one of the most significant vehicles for pursuing global competitive advantage (Hinterhuber and Levin 1994).

If strategic alliances were the dominating forms in the 1990s, how will these be influenced by increasing demands for more responsiveness and agility? 'Just as the strategic alliance has become the popular phrase to describe the growing inter-organisation form of the 1990s, so does it seem probable that virtual corporation will fill that role in the first decade of the new millennium' (Faulkner 1999). There is no commonly agreed definition of a VO. People with different experiences or from different disciplines have used the term to mean different things (Travica 1997, Palmer and Speier 1997, Franke 2002).

Similarly a few years ago 'virtual manufacturing' was used to describe the use of virtual reality and its techniques in the area of manufacturing engineering (Banerjee 1998). Most recently, however, the meaning of 'virtual manufacturing' has been extended to signify inter-firm relationships used to form a temporary supply chain (Miscioscia 2001).

There are at least three main reasons why virtual organisations and—specifically virtual manufacturing organisations—are thought to be emerging. The first is market change (Kotler 1999). As customers' demands become more diverse and fragmented, companies are finding it better to offer a more integrated, solution-based service rather simply selling a product. Many companies are similarly finding it advantageous to move from being traditional manufacturers to become system integrators (Grady 1994, East 1994, Ross 1998, Fuchs 2000). The second reason is partly a consequence of the first reason. As some companies have started to pursue integrated solutions for their customers and as they have begun to outsource non-core manufacturing business, other companies, providing specialised manufacturing services as their own core competence, have been able to emerge to fill the gap between the system integrators and the raw material and/or functional module providers (Serant 2000, Miscioscia 2001, Ojo 2001). The third reason lies in the substantial opportunities arising from new information and communication technologies (ICT). These opportunities not only help smaller new-comers to access markets which were formerly the preserve of global corporations but also provide benefits for the global corporations themselves by allowing them to restructure their operations. The transparency of the value chain, which ICT can provide, allows companies to reposition themselves in the chain and dynamically collaborate with companies to optimise their business position.

Table 1 reviews and summarises key characteristics of research on GMNs, ISAs, and VOs, and highlights their differences. There are many overlaps between the concepts the ISA and the VO, e.g. a contractual collaboration and a long-term virtual business network can describe the same relationship as in the case of some OEMs and their CMS providers. If ISAs represent one end of the spectrum of collaboration, VOs represent the other where collaboration is at arm's-length.

3. The emergence of global manufacturing virtual networks

Manufacturing outsourcing is an emerging trend, especially in the electronics industry. It is driven by a strategic focus on core competencies, the pursuit of higher value positioning within the supply chain, pressure to improve return on assets and a desire to provide total solutions to targeted customers. System integrators, original equipment manufacturers (OEMs) and major contractors are all becoming players

Table 1. Review of the characteristics of three organisation types.

Attributes	Global manufacturing networks (GMNs)	International strategic alliances (ISAs)	Virtual organizations (VOs)
Missions and purposes	• Opportunity and capability • Co-ordination + learning • Global expansion driven • Geographic dispersion • Value-adding chain position • Operations coordination	• Capability orientation • Sustainability push • World and future driven • Co-option (collaborating) • Co-specialisation (Core) • Learning and internalisation	• Business opportunity orientation • Responsiveness/agility pull • Niche/emerging market driven • Scanning and identification • Brokering and integration • Networking and positioning
Structures (architectures)	• Strategic business unit (SBU) and international manufacturing strategy • Product family and globally dispersed factory network • Owned by one company • Each factory is a node • Location and dispersion • Integration and co-ordination	• Seriously strategic planning • Stable and close relationship • Four basic forms of ISAs: ○ contractual collaboration ○ consortiums ○ joint ventures ○ equity collaboration	• Strategic fitness planning • Order or project based temporary relationship • Dynamic re-configuration • No equity collaboration • Few stable partners • ICT platform and teamwork
Operations (dynamics)	• Dynamic response mechanism: opportunity identification and swift mobility • Product life cycle (PLC) and knowledge sharing and transfer • Operational mechanisms and ICT network daily co-ordination • Dynamic capability adaptation and network evolution: learning	• Longer term co-operations • Longer term commitment • Sharing strategic resources • Seeking synergy from co-op • Learning and internalisation • 'Running-in' and cultivation • Adaptation and evolution • Internal cultural synthesis	• Temporary co-operations • Shorter term business deal • Strategic competence fitness • Seeking function integration • Sharpen core competences • Fast engagement & work • Responsiveness and flexible • Cyber and global sourcing
Other characteristics	Like self training, personal cultivation and individual capability development	Like a marriage for longer term commitment and harmony	Like a blind-date, or leisure sport teamwork for competition

on the new battle ground for manufacturing and are attracting wide interest. This is in turn stimulating developments in the key field of supply chain management (SCM).

The research community has largely neglected a very important phenomenon, which is gradually becoming increasingly important for all manufacturing industry and which has been caused by the re-configuration brought about by system integrators. This phenomenon is the emergence of professional manufacturing service providers—especially the contract electronics manufactures (CEMs) or electronic manufacturing service (EMS) providers in electronics and telecommunications sectors.

Together the emerging roles of OEMs and CEMs are re-structuring the electronics manufacturing industry. Most of the traditional vertically integrated companies—such as IBM, Motorola, Marconi, Philips, Sony, and Hitachi—are being re-configured as they focus more on total customer solutions, R&D, ICT and marketing and as they increasingly outsource their manufacturing. Outsourcing of manufacturing by OEMs is fostering the growth of a new group of contract electronics manufacturers (CEMs) and allowing them to extend the scope of the manufacturing service they provide to OEMs—to the extent that they are often referred to as electronic manufacturing service (EMS) providers rather than simply CEMs. These CEMs/EMS providers include some key global players such as Solectron, Flextronics, Celestica, and SCI Systems, but there are more than three thousand local CEMs as well. CEMs or EMS providers typically start from a relatively narrow slice of manufacturing activity, such as in printed circuit board (PCB) assembly ('board stuffing') or manufacturing engineering development, but then move on to become involved in a wider range of activities throughout the manufacturing value chain. Miscioscia (2001) reports 'EMS providers are working to offer a complete cradle-to-grave manufacturing solution', whilst Labowitz and White (2001) say CEMs can promise to an OEM 'you bring us an idea, we'll manufacture the entire product and ship it directly to your customer'. They may even develop beyond that to encompass after-sales service.

Traditional relationships between vertically integrated manufacturers, component suppliers and distributors have been largely broken and new networks—between OEMs, CEMs, component suppliers and distributors—are emerging. These networks are, however, very complex and subject to dynamic change.

OEMs and CEMs are, in effect, creating virtual enterprises, typically led by OEMs. The OEMs gain both flexibility and concentration of key resources. Competition—especially from new-comers like Cisco and Dell, which have neither manufacturing experience nor the associated resource 'burden'—is forcing a sharper strategic focus and demanding the creation of higher value and responsiveness throughout the supply chain. As a result OEMs cannot afford to keep comprehensive manufacturing resources waiting for potential customer orders. The risk in holding manufacturing assets is lower for CEM/EMS providers than OEMs, since they can offer their capacity to a wide range of OEMs.

A new type of manufacturing architecture, which we have called a global manufacturing virtual network (GMVN), is emerging from this scenario. The GMVN extends the concept of the GMN beyond the firm boundary with the term 'virtual' carrying all its connotations of latency, impermanence and dependence on ICT. In a GMVN a lead company does need to maintain internal manufacturing resources to satisfy unpredictable market demand. Rather it depends upon a co-operative resource pool—a virtual network—and then constructs an actual supply network to deliver a customer required solution once it identifies a customer or receives a contract. The GMVN is thus based not on resource ownership but on resource leverage and collaboration.

In the electronics industry, OEMs and CEMs/EMS are already co-ordinating their specialised resources in this way. The OEMs and CEMs/EMSs each play an equally important role in GMVNs, although CEMs are easily overlooked since OEMs are more visible through their brands and are closer to the final consumers.

Although it may not be part of their strategic plan, CEMs and EMS have the potential to develop their own brand names and so transform into OEMs. Conceptually each player in a GMVN has a similar opportunity to identify business opportunities and integrate the virtual network to deliver a solution to a particular customer. Because each one has its own core competence in the network, each could function as part of the many potential chains that could be organised from the collaborative resource pool. The virtual chain, therefore, can be organised to provide responsiveness, high flexibility and efficiency. This type of manufacturing system fundamentally changes the concept of system flexibility; it achieves real market agility and ability to deploy capacity and technology around the globe by externalising flexibility (beyond the firm), by reducing complexity (within the firm), and by accessing the most appropriate resources for a given opportunity.

4. Research design

Figure 1 introduces the main components of the GMVN research. As the key issue of the research is to understand the GMVN like an emerging system, a methodology based on case study observation has been adopted by the research team.

In the first stage of the project, individual companies in possible GMVN sectors with potential GMVN characteristics have been interviewed in order to understand their evolution paths and to identify specific GMVN leads. During the last three years, more than 70 companies in eight industry sectors such as electronics, home electronic appliances, garment, pharmaceuticals, biopharmaceuticals, and aerospace, have been studied in the UK and China in order to identify whether GMVN has emerged from the traditional business models.

In the second research stage, the research priority shifted from pure company-based case studies to studies balanced more equally on the firm and sector levels. The sector observations from leading companies and a wider scope of interviews provide a more general overview on development trends and the hidden drivers of GMVN.

In the third stage of the project, GMVN network observations are being conducted to explore more detailed decision processes, collaboration mechanisms, and evolutionary paths in interactive relationships. Currently, the GMVN-based case studies—mapping a GMVN life cycle in its business network—are still being studied. This paper therefore is mainly to report some interesting findings from the first and second stages of research work.

5. Case studies

This section briefly presents two industrial cases in order to demonstrate the fundamental changes in

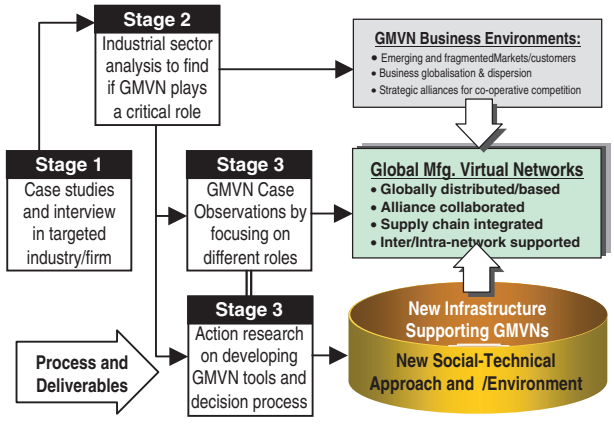

Figure 1. Global manufacturing virtual networks (GMVN) project research process and key deliverables.

manufacturing crossing many sectors. The four cases are in different research stages; the material for the first case has been drawn from industry interviews within the supply network and from secondary research, but as yet no primary research has been conducted yet within the principal companies; it is included as it potentially offers considerable insight into the evolving nature of GMVN. The reasons for choosing the cases are to illustrate the popularity of GMVN in industry as well as some key characteristics of GMVN.

Case 1. Software programmer 'manufactures' video game consoles

The world's largest software company has been involved in the gaming business for some time. It holds a dominant position in the $1.4 billion PC-game market, especially in the online game sector. Owing to its background as a software company, it had not become involved with the video game console business before 1999, yet it coveted a share of the more than $5 billion market shared by three Japanese companies. The case company felt particularly nervous when it predicted that the potential Japanese competitors would soon provide accessibility to the Internet in their game consoles and so penetrate its dominant arena. To respond to the potential competition proactively, it claimed it would introduce its own video game consoles with superior functionality.

Although the case company is very rich, it is never easy for a newcomer, especially one without any hardware production experience and or production capacity, to penetrate an already crowded market. Mapping the video game supply network, a software company could potentially find its position in the network by providing game programs or even entertainment design—see figure 2. In contrast it would be very difficult to establish its own manufacturing capability for a console containing more than 3000 components in order to compete head to head against the established giants like Nintendo and Sony. In the early 1990s Sony spent more than four years building up its capacity to launch its PlayStation console having started from a joint venture with Nintendo. To win the game, the case company realised that it had to find a new way to build up its capability in order to reduce the time to the market, the costs to final customers, and the risks to itself. Collaboration seemed to be the only way.

Outstanding functionality was, of course, critical for its new product. Some strategic components (table 2) were tailored to its unique requirements to ensure its console's superiority. However, acquiring these components was not really the challenge in delivering the finished goods in a very short time and at an affordable price to its customers world-wide. By contrast manufacturing and logistics for the 3000 components were difficult issues for a software company. The case company initially contacted Gateway and Dell, but was not satisfied, mainly because these companies rarely make anything either. It then quickly focused its search on the electronics manufacturing service (EMS) providers, to find manufacturing and logistics solutions.

The emergence of EMS is a result of the re-structuring the electronics manufacturing industry. Most of the traditional vertically integrated companies or original equipment manufacturers (OEMs), such as IBM, Motorola, Marconi, Philips, Sony and Hitachi, have been strategically outsourcing their manufacturing operations by de-merging manufacturing activities and re-focusing on total customer solutions and related R&D, as well as on new technology and marketing. Outsourced manufacturing from OEMs formed the

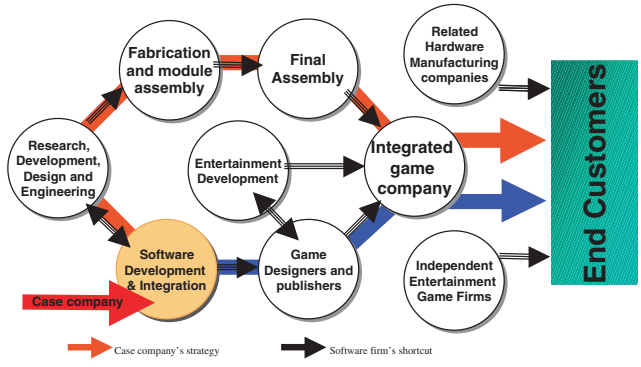

Figure 2. A network for an integrated game company.

Table 2. Key features comparison between different game controls.

	PlayStation 2 (Sony)	GameCube (Nintendo)	Case company product
Processor	95 MHz Sony	485 MHz Power PC	733 MHz Pentium III
Graphics chip	147 MHz Sony	203 MHz ATI ArtX	300 MHz Nvidia GEForce3
Total memory	32 MB	40 MB	64 MB
Operating system	Proprietary	Proprietary	Modified Win 2000
Built in Internet access	No	No	No
Key partners	Toshiba	Matsushita, IBM	Intel, Nvidia

nucleus for the new group—electronics manufacturing service (EMS) providers. They offer a radically wider scope of manufacturing service to OEMs compared to the more traditional 'board stuffers'. These fast-growing EMSs have become global players with sales in excess of £10 billion.

EMS providers may start from the relatively narrow scope of manufacturing services, such as in printed-circuit boarder (PCB) assembly or manufacturing engineering development, but then move on to become very aggressively involved in the whole manufacturing chain and then even beyond that towards after-sales service. 'EMS providers are working to offer a complete cradle-to-grave manufacturing solution' (Miscioscia 2001). Nowadays CEMs can promise to an OEM that 'you bring us an idea, we'll manufacture the entire product and ship it directly to your customer'. The traditional relationship between vertically integrated manufacturers, component suppliers and distributors has been largely broken; and new networks between OEMs, EMS, designers, component suppliers and distributors are emerging. These networks are, however, very complex and dynamic.

The case company chose one of the leading EMS providers—subcontracting not only all manufacturing tasks from PCB assembly, final assembly, testing and packaging but also most logistics co-ordination work to it. The case company holds only some strategic commodities including Intel CPU and Nvidia Graphics chips. As the chosen EMS has widely dispersed manufacturing facilities, the case company believed it could both satisfy the requirement for rapid ramp-up of volume and serve the world market. Indeed, with the EMS and the collaborative network support, it launched its video game console in late 2001, in only half of the time of its competitor's first trial.

Case 2. Leisure garments made by virtual manufacturing

Like many Chinese entrepreneurs emerging in the early 1980s, the owner of the case 2 company started his garment manufacturing business in a very modest way, but vertically integrated way—designing, processing and selling all kinds of clothes from suits, jackets to windbreakers. In 1992, with the popularity of windbreakers and jackets and serious shortage in production capacity, he rented a factory and ramped-up large volume production for seasonal products. In just that year, he made a fortune and achieved sales of £0.5 million. More importantly, he quickly realised that he could achieve much faster growth by subcontracting his production to established contractual manufacturers, whilst at the same time developing its own brand name and control selling and distribution in the Chinese domestic market. Based on these rough ideas, he registered a new company in 1994 with £300 000 capital and started his virtual manufacturing adventure.

This company was based in the southern east part of China near Shanghai. It lacked the financial resources to develop its production capacity, but it found that the Pearl River Delta (PRD) region had a very mature group of manufacturing resources, which were very for orders. It decided to subcontract its production tasks to these contract manufacturers in the PRD region. It was very challenging work. Firstly, it needed to have a 'breakthrough mindset'. Traditional Chinese manufacturing industry was so self-reliant and fully vertically integrated. Doing manufacturing business without manufacturing capacity was unthinkable for both internal and external stakeholders. Secondly, trans-regional integration and co-ordination were also very difficult. Especially in the early stage, the case company did not have the technology and experience to run this type of virtual network; everything depended upon its entrepreneurial spirit and a good co-operation within the core team. Thirdly, when the company reviewed its seven year path of virtual manufacturing, it found that it would not have been able to reach its current stage in such a short period, and with very limited financial resources, had it followed the traditional organic development route or pursued a vertical-integration model. The virtual manufacturing model also helped the company achieve lower operating costs and high flexibility to coping with radically changing fashion and leisure garment markets.

Within just seven years, the company achieved a net capital £15.4 million, sales of more than twenty million units, and a turnover of more than £115 million in 2002—based on its network of over 200 contract manufacturers and a nationwide distribution chain with over 800 stores.

6. Conceptual frameworks

A research field cannot be fully developed until there is a framework and an accepted core of theoretical ideas (Teece *et al.* 1992). When a multinational corporation integrates its globally dispersed factories into a globally co-ordinated factory network, it usually not only links its own manufacturing resources together but also integrates its supply networks worldwide. It is obvious that inter-firm global supply networks are more challenging to manufacturing managers because of their recent emergence and their complexity. However, a company which can manage a GMVN effectively will be in a much stronger competitive position. Moving from a GMN to a GMVN will entail many changes, but the

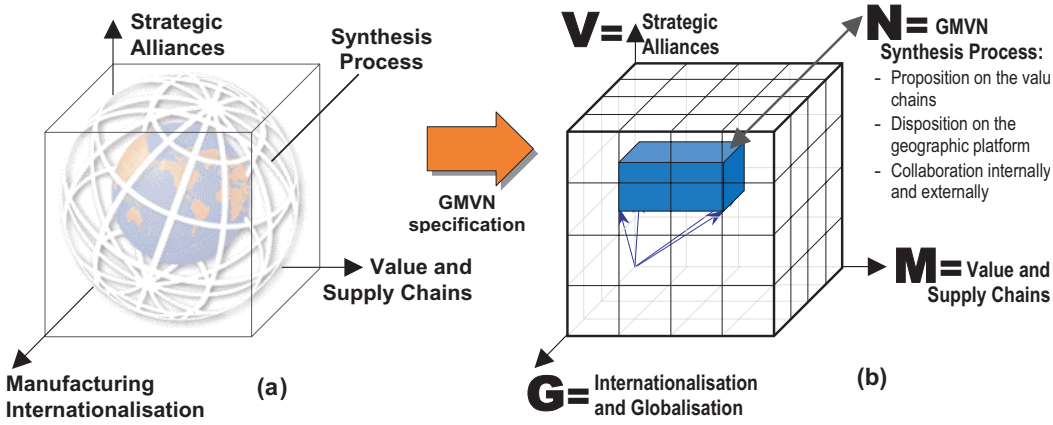

Figure 3. Manufacturing system contexts and GMVN position.

fundamental change is that the manufacturing system now crosses the firm's boundary and into a complex inter-firm relationship. The change in paradigm from GMN to GMVN can provide manufacturing managers with a broader range of options to organise manufacturing resources more effectively and efficiently. A generic three-dimensional strategic environment for manufacturing system design is developed in figure 3(a). Four key decision areas must be addressed in order to design and operate a manufacturing system:

- *Manufacturing internationalisation*. The manufacturing system is no longer a single site factory. Decisions must be made concerning geographic expansion or repositioning. In the process a company must consider its international expansion plans in the context of its history and must explicitly address issues of cross-cultural integration.
- *Value and supply chains*. The manufacturing system and its tasks must be defined along the supply/demand chain or value-creation network by configuration (defining the manufacturing activities required in the value chain), position (that part of the value chain to be directly controlled by a company) and optimisation (selection of partners, grouping and disposition of activities for internal and external manufacturing resources, systems, etc) to achieve higher value and competitive advantage.
- *Strategic alliances*. A spectrum of potential collaboration modes, including intra-firm co-ordination and inter-firm co-operation, has to be evaluated. In inter-firm collaborations, there is a wide span of choices from strategic alliances (for longer term commitment) through virtual communities to arm's-length trading relationships (for more flexibility).
- *Synthesis process*. The above three dimensions cannot be considered independently in the current global competitive environment. It is essential to synthesise them into an integrated manufacturing system supported by a systematic strategy process and the most appropriate technology (including the cyber platform).

Thus according to our preliminary understanding of industrial requirements and manufacturing research, a GMVN can be considered as a synthesis of views along three basic dimensions in figure 3(b):

- **G**lobal disposition and the evolution of manufacturing internationalisation are represented on the manufacturing internationalisation dimension, '**G**'.
- Value-creation oriented **m**anufacturing activities and positioning are represented on the value and supply chains dimension, '**M**'.
- Collaborations with other companies to formulate a strategic alliance or temporary **v**irtual supply chain are represented by the strategic alliance dimension, '**V**'.

These three dimensions must be integrated by a synthesis process '**N**', which must include **n**etwork strategy process, communication platform and operational mechanisms. Figure 3(b) illustrates that the GMVN represents a relatively small part of this three-dimensional space; other manufacturing systems are appropriate in other positions.

In traditional manufacturing system design, especially at the factory decision level, the internationalisation (G), and collaboration (V), dimensions are rarely considered. Similarly the value/supply chain position (M axis) is simply represented by the 'span of manufacturing process' (Hays and Wheelwright 1984). Current research on manufacturing systems and operations management is still limited to two-dimensional constructs—either on the GxV 'plane' dealing with

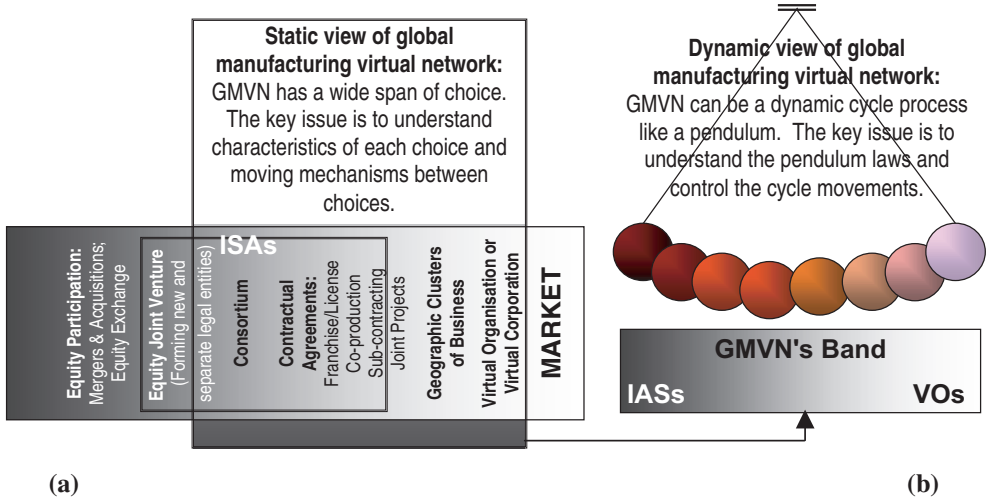

Figure 4. Different views on GMVN.

internationalisation and alliances or the GxM 'plane' dealing with supply chain and internationalisation (Harland *et al*. 1999). The synthesis process, N, in figure 3(b) has been largely neglected and this inhibits the development of comprehensive understanding of GMVNs.

As they involve manufacturing systems, GMVNs must be differentiated from generic virtual organisations. The latter could involve a pure broker subcontracting anything and everything. But manufacturing companies, especially global players, have to own some essential process-based resources, such as technology, facilities, equipment, capacity, and even organisation. Future development is largely dependent upon resources and from this viewpoint the GMVNs' role is sit between ISAs and VOs. Therefore, the 'virtual' character of GMVN's must be understood in this unique context.

Figure 3 also provides an analytical tool to capture some key features of industrial transformations. Taking an evolutionary perspective of the electronics industry, it has been observed that, during its globalisation from the 1980s to the mid-1990s, many multinational companies extended their manufacturing systems worldwide but retained hierarchical control and vertical integration. However, after the mid-1990s, OEMs reduced the span of manufacturing process they controlled directly and used outsourcing and collaboration to develop a virtual manufacturing system with which to exploit global opportunities. This eventually helped both OEMs and EMS providers achieve more potential for growth in global new-technology markets. The three-dimension model (figure 3) helps manufacturing managers to design the architectures and mechanisms of these new manufacturing networks, by making explicit those elements which must be integrated.

If ISAs and VOs are placed in a spectrum, as in figure 4(a), the GMVN covers quite a wide span of this spectrum. The GMVN can combine the appropriate balance of the virtual organisation's flexibility to capture business opportunities and the ISA's ability to develop capabilities and relationships. Its fundamental characteristic is not a hierarchical organisation as in a global manufacturing network (GMN), i.e. an internal manufacturing system, which is vertically integrated. It is instead an inter-firm network or a relationship. This, however, may be regarded as a static view of the GMVN's architecture.

The dynamic view of GMVN as a network of collaboration between different companies, is much more interesting (figure 4(b)). It may be regarded as a pendulum moving between VOs and ISAs changing the relationships between OEMs and CEMs. In other words the nature of relationships in a GMVN is not fixed; it changes in response to market requirements. A small specialist manufacturing service provider might spot an opportunity and 'activate' a value chain from GMVN members. Over time experience with the project will enable players to develop their core competencies. If the project is successful and enduring it could become core business for some of these players. At this stage, the lead company's concern is how best to manage this activity over the longer term; it may, for example set up more binding ties with its partners or alternatively it might internalise some of the activities, which were initially outsourced to GMVN partners. As each partners' core competences develop, it is more able to identify/access

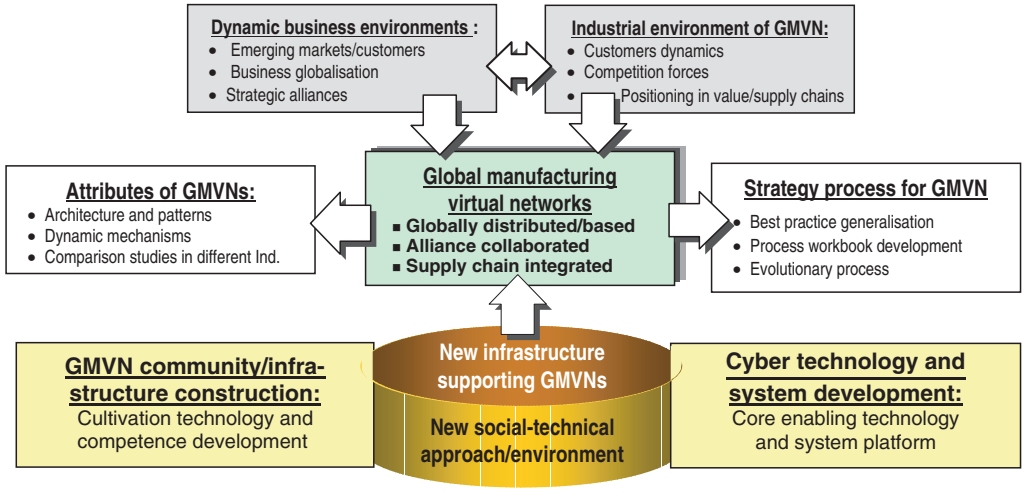

Figure 5. A research framework for global manufacturing virtual network development.

new market opportunities, which may in turn be exploited by starting another GMVN. This dynamic model may help managers adopt a more evolutionary vision and avoid competence traps.

7. Further research on GMVN

Although GMVNs have been observed in several industry sectors such as electronics, automotive, and even aerospace, we still have a lot to learn in order to understand these virtual networks fully and to design and operate them successfully. Such understanding will only come from a close collaboration between academics and practicing managers.

From a research perspective, further detailed studies on GMVNs should include three main strands:

- The GMVNs' environmental and industrial sectors: this will help clarify the main driving forces for the emergence of GMVNs and identify for which other sectors GMVNs would be an appropriate manufacturing system.
- The characteristics of the GMVN system: this will enable us to understand GMVNs' attributes in terms of its main building blocks, its architecture, its dynamics and its management processes. It will also help formulate a strategy and design process for developing an effective GMVN.
- The key new technology and infrastructures for building and operating GMVNs: this includes the design and operational techniques for systems which will facilitate the establishment of a GMVN community together with the necessary ICT platforms and infrastructures.

Figure 5 demonstrates these three strands of the research work and places them into three layers and six major research modules.

8. Conclusions

Manufacturing industry has been changed dramatically as brand-owning businesses have changed their business model towards providing individual client-based solutions rather than simply manufacturing and selling products. However, studies of international strategic alliances and virtual organisations have paid little attention to the manufacturing networks that are emerging from this transformation, nor to the implications for the structure and operation of supporting communication systems. Understanding the nature of these new global manufacturing systems and the emerging electronic commercial and communication environment is fundamental to our appreciation of the implications of e-business for manufacturing worldwide.

In this paper, a specific class of manufacturing system—the GMVN or global manufacturing virtual network—has been identified and its characteristics and potential have been outlined. The potential of GMVNs to enhance a company's ability to exploit competences has been introduced. The concept of the GMVN is especially important for manufacturing companies, when their business is shifting from product manufacturing to providing solutions; the electronics and telecommunication may lead in this development, but it is appropriate for engineering, automotive and aerospace sectors as well. Future work is proposed to understand GMVNs better at three levels (figure 3) and

to develop practical decision tools and strategy processes for GMVN formation and operation.

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