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Margaret Webster, David Sugden

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Margaret Webster and David Sugden
University of Bradford School of Management, Bradford, UK

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Abstract *The paper considers the implementation of a virtual manufacturing system as an alternative to outward technology licensing in a high technology industrial sector. Brief theoretical definition and description of the two strategy options is provided to give background and context. This is followed by empirical material from a longitudinal case study of a company that has developed a virtual manufacturing system in addition to its pre-existing outward technology licensing business stream. A summary account of the company history and development is followed by description of the virtual manufacturing proposal. Analysis of this identified a number of competencies that would be required in order to succeed. The final part of the paper describes the company's response to this analysis and discusses early implementation of the virtual system. It is shown that implementation of the proposal has represented a positive response to the business challenges facing the company.*

Introduction

Organisations within contemporary business environments are increasingly required to react and cope with competitive pressures deriving from a variety of sources. These include the globalisation of economic activity, increased innovation and rapid technological change and the increased power of customers (Barnes and Hunt, 2001, p. 139). Virtual systems are emerging as business models that aim to integrate market, product, and manufacturing strategies for the twenty-first century. It is said that the virtual organisation may provide the flexible, cohesive and synergistic business model necessary to operate successfully in the current business climate (Barnes and Hunt, 2001, p. 139; Introna, 2001). The agility associated with such fluid and flexible organisational forms is key to providing efficient and effective response to increasingly sophisticated customer demands. With this in mind, the work presented in this paper sought to address two principal research questions:

RQ1. Does the virtual manufacturing model offer a commercially viable operations strategy for the exploitation of product-related technology?

RQ2. What competencies and capabilities are pre-requisite to successful implementation of such a strategy?

The paper considers the implementation of a virtual manufacturing system by a company that had previously operated with only a technology licensing business stream. It presents theoretical background material to give context to

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the case study that is the subject of the main part of the paper. This includes definition and discussion of virtual manufacturing. An account of the company history is followed by a description of the virtual system proposal. This has been analysed in order to identify the competencies necessary for successful implementation. The means by which the necessary resources and skills were acquired and/or developed is followed by a description of the current status of the operation. The significance of the work is highlighted.

Background and context

The appropriate choice of operations strategy is key to the commercial success of any enterprise and is a critical issue for operations management. For companies that manufacture products, strategy options have been modelled on Williamson's organisational continuum, and range from "internalisation" to "contracting" (Toms and Filatotchev, 2002; Williamson, 1975). These options map to conventional and virtual manufacturing, respectively. The emphasis in this model, however, and in much of the seminal work within the operations strategy field (e.g. Skinner, 1985; Hayes and Wheelwright, 1984; Hayes *et al.*, 1988), has been on strategy development for *ex ante* manufacturing businesses. For companies with a non-manufacturing background, such as those that develop and sell technology, the Williamson continuum needs to be extended through contracting to exploitation options that do not require any involvement in product manufacture (Webster and Sugden, 2001a).

Alongside operations strategy, recognised technology and innovation strategies are seen as integral parts of an overall strategic architecture to inform and equip an organisation for operating within the new global business environment (Banerjee, 2000; Phaal *et al.*, 2001). Central to the innovation strategy of manufacturing companies, is the make-or-buy decision relating to technology development activity – of product and/or process (e.g. Cáñez and Probert, 1998; Chiesa *et al.*, 2000). For some companies, a more appropriate decision may to be "make-and-buy" (Veugelers and Cassiman, 1999). By contrast, the innovation strategy of technology developers – particularly those that develop product technology – involves the decision either to profit from the sale of the technology (e.g. by licensing-out) or from self-exploitation (by conventional manufacturing) (Arora *et al.*, 2001). Put more crudely, the decision can be thought of as one of "use-or-sell", with the additional possibility of "use-and-sell". Resolution of the decisions to make/buy or to use/sell within the innovation strategy of an organisation, is inextricably linked with the choice of operations strategy on the continuum from conventional manufacturing, through virtual manufacturing, to outward licensing.

In order to provide sufficiently detailed theoretical context for the case study that is to follow, the remainder of this section of the paper considers strategy options for the exploitation of product technology. Virtual manufacturing is considered in some detail, as this represents an option for both *ex ante* manufacturing companies as well as for those that traditionally "sell" product technology. It also represents an emerging business form of contemporary interest within the operations management field.

Operations strategies for the exploitation of product technology

For organisations that are involved in new technology research and development, exploitation routes generally exist through the design and sale of products. For these, much of their competitive advantage derives from the successful protection of the technology leading to retention over its control, and from an ability to effect rapid market penetration. These twin objectives inform the choice and implementation of operations strategy, which traditionally have ranged on a continuum between the two extremes of licensing-out (selling) and conventional manufacturing (using). These involve the development and use of altogether different operations capabilities and competencies.

Outward technology licensing is an exploitation mechanism whereby independent organisations pay for protected design data and the right to use the technology in production processes or in products that they manufacture and sell as their own (Lowe and Crawford, 1984a, b; Arora *et al.*, 2001). A licence can be defined as an agreement by which one company (the licensor) grants another (the licensee) the right to use its intellectual property for a defined purpose. The technology originator (licensor) generally profits from the payment of up-front fees and on-going royalty fees in proportion to the commercial success of the exploited technology. It usually has no involvement in the manufacturing process. In general terms, the use of technology licensing supports the increasingly advocated business strategy of focus on core competencies. The licensor retains its competence in technology development and the licensee concentrates on its competencies in the exploitation of technology through product manufacture (Webster and Sugden, 2001a, b).

At the other extreme is the establishment of comprehensive in-house manufacturing facilities in order to build products designed around the protected technology, thus "using" it directly. In this scenario, the technology originator is required to develop a full range of competencies in the manufacturing processes used and in activities that support the manufacturing function. This option requires significant investment in manufacturing facilities and supporting resources.

However, to keep investment costs under control and to restrict uncertainties about the manufacturing capabilities of the company, an operations strategy based on a disaggregated or extended enterprise could be envisaged (Banerjee, 2000). This strategic architecture is increasingly linked to the concept of virtual manufacturing, which presents itself as an alternative business model (e.g. Christie and Levary, 1998; Reid *et al.*, 1996a, b; Schumacher *et al.*, 1996; Introna, 2001). This involves the creation of networks of independent agents, each specialising in their own key skills. The true virtual manufacturer has no internal manufacturing capability at all, but outsources all physical production functions to suppliers and subcontractors. By marshalling external competencies, a virtual environment is said to improve responsiveness, product and process design, manufacturing design and operation, and to reduce manufacturing risk (Gunasekaran, 1999). A virtual manufacturing system is fluid and re-configurable. It has the agility to be both highly responsive and highly flexible in the light of dynamic customer needs. Using this approach to technology exploitation, the technology originator could design and develop "own-label" products, but use a network of independent suppliers and subcontractors for manufacture. This represents an intermediate position on the continuum described and requires a compromise in terms of skills and competencies. The organisation is required to organise, manage and plan manufacturing but it is not required to develop specific manufacturing process skills or to invest in manufacturing resources (Webster and Sugden, 2001a, b). However, it is benefiting from "using" the developed technology, rather than from "selling" it.

Virtual manufacturing

The virtual enterprise is widely discussed as an emerging organisational form that may be able to meet the challenges of operating in business in the future. However, there is confusion over the concept of virtuality and, more specifically in relation to this paper, over the definition and characteristics of virtual manufacturing. This has been defined alternatively as the modelling and simulation of manufacturing systems (Lin and Fu, 2001), of manufacturing processes (Offodile and Abdel-Malek, 2002) and of prototype manufacture (Waller, 1999). The majority of work in the area, however, views it as the manufacture of a tangible product using a network of geographically-dispersed, independent manufacturing partners. It is frequently linked with organisational agility (Meade *et al.*, 1996; Marshall *et al.*, 2001; Harrison, 1997; Katzy and Dissel, 2001). As such, it is sometimes characterised by its temporary formation from a cluster of potential partners (Reid *et al.*, 1996a; Meade *et al.*, 1996; Lackenby and McBain, 1999) in order to respond to a specific business opportunity before dissolution once the opportunity has been met (Marshall *et al.*, 2001; Lau and Wong, 2001; Meade *et al.*, 1996; Lackenby and McBain, 1999). A virtual manufacturing network, while consisting of separate partners, gives the appearance of acting as a single enterprise (Rupp and Ristic, 2000; Rautenstrauch and Turowski, 1999; Lackenby and McBain, 1999). Its defining characteristics and features are generally agreed to be networked manufacturing (Upton and McAfee, 1996; Lau and Wong, 2001; Panteli and Dibben, 2001); geographical dispersion (Lau and Wong, 2001; Rupp and Ristic, 2000; Panteli and Dibben, 2001); and strategic alliances and partnerships (Introna, 2001; Rupp and Ristic, 2000). There is less general agreement, but some consensus as to the temporary nature of the enterprise and the essential use of information technology (IT) to manage the partnerships involved.

Critical success factors for virtual manufacturing have been proposed. These include the effective management of order flow, production planning and scheduling (Richards *et al.*, 1997; Rupp and Ristic, 2000; Schumacher *et al.*, 1996); trust and co-operation among partners (Lackenby and McBain, 1999; Marshall *et al.*, 2001; Katzy and Dissel, 2001); and shared purpose, risk and benefit (Marshall *et al.*, 2001). There is additionally a considerable body of thought proposing that appropriate use of sophisticated IT is critical to successful implementation (e.g. Upton and McAfee, 1996; Schultze and Orlikowski, 2001; Rautenstrauch and Turowski, 1999; Martinez *et al.*, 2001). However, this proposal is countered by others who do not regard the use of IT as essential (Quereshi and Zigurs, 2001; Panteli and Dibben, 2001; Katzy and Dissel, 2001). Lau and Wong (2001) identify the selection of manufacturing partners and the capability of the information flow infrastructure (not necessarily technology-based) as key facilitators. Katzy and Dissel (2001) argue that in implementing virtual manufacturing, there is a need to move away from traditional decision and planning systems, such as MRP/ERP. These, they argue, prevent fast reactions (essential to agility/virtuality), and lead to the need for innovative approaches in order to ensure success.

Few authors specifically consider the reasons for the existence of virtual organisations. However, as mentioned above, they are frequently linked with the pursuit of agility, where agility is the capability to succeed in situations of unpredictable change (Katzy and Dissel, 2001). Having the ability to temporarily and co-operatively configure resources and competencies from a geographically-dispersed network of independent partners provides the means to bring products to market in minimum time (Harrison, 1997). From the perspective of *ex ante* manufacturing companies, adoption of a virtual approach is said to benefit SMEs by facilitating the development of the critical mass normally associated with a larger firm (Lackenby and McBain, 1999) and to benefit OEMs by providing advantages associated with margins, capital, time-to-market, geographic expansion, flexibility and specialisation (Ansley, 2000).

A general lack of empirical work in the area of virtual manufacturing and of published practical experience with this form of organisation has been noted (Marshall *et al.*, 2001; Schultze and Orlikowsky, 2001). Limited work has been reported, but this has focused on cases of the adoption of a virtual approach by individual (or networks of) *ex ante* manufacturing companies (e.g. Richards *et al.*, 1997; Siqueira and Bremer, 2000; Reid *et al.*, 1996a; Katzy and Dissel, 2001; Gordon and Gordon, 1996; Ansley, 2000; Webster, 2001). Indeed, Reid *et al.* (1996b, p. 485) argue that "among the most interesting competitive strategies being explored by manufacturing firms is the concept of the virtual enterprise". Discussion of the adoption of the virtual approach by non-manufacturing companies is noticeably absent from the literature. Similarly, apart from a few rather imprecise accounts (e.g. Upton and McAfee, 1996; Ansley, 2000; Gordon and Gordon, 1996) there is a dearth of work describing the practical implementation of virtual manufacturing. This suggests that there is a need for empirical research to corroborate or counter the theoretical perspectives on virtual manufacturing. The empirical work to be presented in this paper addresses this research gap. It provides detailed practical findings from a single longitudinal case study about the reasons for adopting virtual manufacturing, about its implementation and about its ability to contribute to business success. The case concerns the implementation of virtual manufacturing by a company that had previously used only outward licensing to generate business success.

The remaining parts of the paper present an account of the methodology used to develop the case study, company history, background to the decision to extend operations strategies, and a description of the virtual manufacturing system. The analysis of company competencies that was carried out at the proposal stage is then used to frame a discussion of the early implementation of the virtual manufacturing system. Throughout the case description, where appropriate, the decisions and actions taken are discussed in relation to the theoretical perspectives provided in the early part of the paper.

Methodology

According to Parker (1991, p. 19) "organisations exist to develop or perfect technologies, and then license them. Their business is technology development for sale". This scenario applies to the company that has collaborated with this work. Although this type of business is not unique, it is relatively rare (Arora *et al.*, 2001). The research significance of the longitudinal case study developed from investigating unique or rare cases is high (Yin, 1989). The research to generate the case study presented in this paper was undertaken by a combination of action research and detached academic observation and input. (In order to avoid repetitious citation in the text, it is noted here that the description of the methodology relies heavily on the work of Coughlan and Coghlan (2002). Unless otherwise stated, all points made about the action research approach, are drawn from their overview paper of action research methods in operations management).

Action research aims both to take action and to create knowledge or theory about that action. It is a process that fundamentally explores change and is said to be applicable to the understanding, planning and implementation of change in business firms. It requires broad pre-understanding of the corporate environment in which it is carried out, and is therefore considered a suitable approach for an existing company manager to investigate a particular business issue. Interestingly, providing some precedent for the adoption of this approach, one of the few other reported cases of the implementation of virtual manufacturing was based on an action research project (Siqueira and Bremer, 2000).

The research is based on an initial study started in 1998 as an MBA management project by one of the authors (Sugden, 1999). He was, at that time, working in a business development role for the sister to the case company, but subsequently became managing director of the case company. The MBA project work coincided with the launch of an in-company strategy review to consider the option of self-exploitation for the technology that it had previously only exploited by outward licensing. Virtual manufacturing was suggested as an option, and the MBA project incorporated a feasibility study to explore this. This led to a proposal for implementation and an analysis of the competencies that would be required to bring about success. The research has continued since submission of the MBA report in December 1999, and remains actively undertaken in parallel with the operation of the business. During both the MBA project and the subsequent implementation and operation of virtual manufacturing, the in-company actions have been supported by a process of reflection and learning. This has been facilitated by the involvement of an independent academic, initially as MBA project supervisor and thereafter as independent observer. The role of the academic has been to encourage the appropriate analysis of plans made and actions taken, in order to ensure that the action research cycle has been rigorously applied and that the processes of data exploration have been undertaken in a methodical and orderly way. The longitudinal case study, started formally in 1998, continues to develop as a result of the deliberate action research process of "planning, taking action and evaluating the action, leading to further planning" (Coughlan and Coghlan, 2002, p. 223). It meets the requirements for action research because it is both participative (on the part of the in-company researcher) and concurrent with the action that is taking place within the company.

Case study

Company history

For reasons of commercial confidentiality, identification of the collaborating firm is not possible, and it will be referred to as TLC (for Technology Licensing Company). The company designs and develops electrical motors and controllers using design-protected technology which gives improved product performance at lower cost than conventional motor technology. The founding technology from which TLC originated was developed by research staff at two UK universities in the late 1960s and, at that time, represented a significant advance in product technology. Commercially protected, industrially-sponsored research into the technology followed and related product development continued throughout the 1970s. In 1980, the industrial sponsor withdrew, and the founding academics established TLC as a commercial enterprise for the licensing of the developed technology. The rationale behind this decision was based on the core competencies of the founders who had little experience of product manufacturing or marketing, but considerable expertise in engineering research, design and development. This expertise included the very low volume manufacture of prototypes of products incorporating the technology, built for actual and potential licensees. This activity involved in-house workshop-based assembly of externally sourced components, and led to the development of skills in managing prototype manufacture. At this stage, the founders were confident of the commercial viability of the technology, but less sure of their competence in managing full-scale exploitation through conventional manufacturing. It was further felt that by selling the rights to exploit the technology, minimal investment in the newly-founded enterprise would be required. Up-front fees would cover continuing research and development costs, while profits would derive from royalty receipts. This strategy accords with the ability of entrepreneurial start-ups to appropriate returns on their innovation efforts without the need to mobilise the substantial resources needed for internal application (Arora *et al.*, 2001).

Following the acquisition of a site, the technology development and engineering team was increased, and considerable commercial success followed. By the early 1990s TLC's pioneering technology was much in demand. Potential users were restricted either to licensing it in or to risk infringing TLC's intellectual property rights. At that time, a major global corporation (with annual sales in 1994 of $8.6 billion) wanted to expand its technology portfolio into the area developed by TLC. It was already operating successfully in the research, design, development, manufacturing, marketing and sales of products in industrial automation, industrial process control, domestic appliance technology and motor technology. In order to provide licence coverage for all its potential applications, however, it would have needed to buy many licences. Instead, it made more financial sense to purchase the company itself. Thus, ownership of TLC transferred from the original founders to its new global parent. The acquisition of TLC also meant that the parent company now had strategic control over the release to competitors of the specialist technology. Since that time, TLC has continued to operate as a quasi-independent unit within its larger corporate environment.

With the change of ownership came pressures to change the mode of company operation. TLC was to undertake an intensive patenting programme in order to fully protect its intellectual property, and was only permitted to license out its technology to firms that did not compete with any subsidiaries of the owner. Additionally, commercial pressures began to restrict the success of the licensing of the original technology. Competitors were developing similar technology, high investment costs restricted potential licensees to large companies, and investment costs in further internal development of the technology were high. The parent company, with its primary focus on mass product manufacture and sale, was uncertain of the value of further investment in development at TLC. Company survival, therefore, depended on a change of operations strategy that could be shown to have potential to generate commercial success into the future.

Staff at TLC remained confident that many potential applications of controlled motors, built using their technology, existed. These included applications in electrical products manufactured by small companies that do not have the technical or financial ability to license-in TLC know-how. For them, use of TLC technology offers the potential to provide market edge and to expand business through price savings, improved product performance characteristics, customisation to specific needs and the provision of marketdifferentiation for their end-products. These organisations represent an untapped market where, typically, they now buy off-the-shelf motors, built using conventional technology. The number of enquiries received by TLC from buyers seeking motors incorporating the technology far exceeds the number of enquiries by potential licensees.

At TLC, in order to pursue these perceived opportunities for growth within the restrictions placed on them by the parent company, the concept of a "product incubator" (a term coined by the company) was born. This was envisaged as a product development and manufacturing environment based on principles of virtual manufacturing. It aimed to make and sell products to customer order, generally in low volumes and at low cost to the customer, but at high profit. It was to be established with minimum capital outlay. A model for the structure and operation of the product incubator follows.

Product incubator proposal

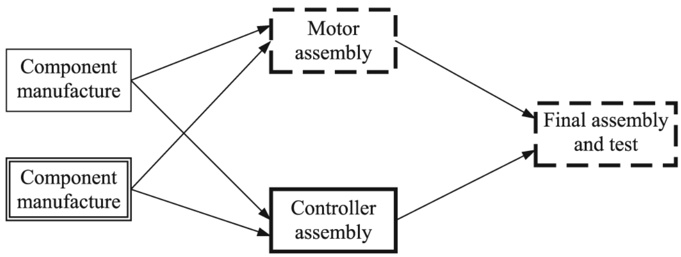
The majority of customers for controlled motors using TLC technology are industrial original equipment manufacturers (OEMs). The motors are incorporated as components into a range of domestic and industrial end-products. Typical applications involve the use of a variable speed electric motor operating outside the range of conventional technology, such as operating at high speed or operating in hostile environments. They include industrial and commercial sliding doors, washing machines, underground mining conveyors, air-conditioning units, laboratory centrifuges and industrial air compressors. Profit margins tend to be greater for high-power motors produced in low volumes (e.g. for mining applications) than they are for low-power motors that are made in high volumes (e.g. for washing machines). Additionally, for high-volume, low-power motors, minimal variety means that dedicated flowline manufacturing systems are able to achieve short lead times. By contrast, for the low-volume, high-power motors that are often built to order, lead times tend to be protracted. Manufacturing systems for this market sector require flexibility. It was the intention of TLC to compete on the basis of price and lead time on controlled motors primarily in the low-volume, high-power sector. It intended to identify specialist products for niche markets and to be responsive to these opportunities as they arose. TLC Manufacturing Ltd. (TLCML) was to be established as a separate company operating within a purpose-built facility at the TLC site.

The complexity of the TLC technology and of products built using it derives from the innovative use of the technology within motor and controller design, and from the specialist manufacturing processes associated with parts of the product-build. A standard product consists of a motor linked to a separate electronic controller. The components for the controller, including custom-designed parts incorporating TLC technology, can be sourced from a number of manufacturers. The motor, on the other hand, requires highly specialised manufacturing processes which are not widely available. Assembly of the motor and controller into a finished product is followed by full product test. As mentioned earlier, TLC was already manufacturing prototype-controlled motors using a variety of suppliers and subcontractors. The controllers were multi-sourced. An existing TLC licensee, which had a purpose-built assembly and test facility for motors, also acted as a subcontractor and provided these for TLC prototypes. Final prototype assembly and test was achieved in-house within TLC's engineering workshop.

In creating the product incubator, TLCML proposed to build on its prototype activity and to establish a manufacturing system based on a number of distributed, independent manufacturing units. These would include suppliers of both controller and motor components drawn from the existing portfolio of prototype collaborators. Some components would be sourced from sister companies within the parent company. The supply of motors for the incubator was the most critical, as fewer capable suppliers existed and because volumes would be greater than the existing level of prototype activity. In the early planning stages for the incubator, TLCML had intended to develop its own in-house manufacturing facility for motors. However, the existing prototype supplier at that time stopped manufacturing motors under licence and it sold its motor manufacturing facility to TLCML. It was also planned that this remote site be used for the final assembly, test and dispatch of finished products.

At its home site, TLCML would perform business activities such as sales and marketing, customer interfacing, quotations, order-processing and invoicing. It would also be responsible internally for such manufacturing support activities as production planning, scheduling, materials planning and procurement, kit marshalling, controlling, and progressing. Accounting, custom product design and sales agency functions would be sourced to the sister TLC organisation. Figure 1 summarises the network organisation that was to be established to profit from "using" the technology in the manufacture of tangible products. Referring back to the discussion given earlier, it can be seen that the model proposed for the product incubator was derived from principles of virtual manufacturing. It was to be based on a geographically dispersed network of owned and independent supply partners; and it was to (temporarily) configure design and manufacturing capability from partners and strategic allies, as appropriate, in order to respond to niche product development opportunities as they arose (i.e. it was to have agility).

Schematic of the manufacturing process



Note: *Key to the location of manufacturing activity and a summary of the manufacturing (M) and business (B) activities of all network partners*

TLCML home site: (solid thick line)
- *M* Controller assembly
- *B* Business administration: sales & marketing, customer interfacing, quotations, order-processing, invoicing
- *B* Manufacturing support: production planning, scheduling, materials planning, procurement, kit marshalling, controlling and progressing

TLCML remote site: (dashed line)
- *M* Motor assembly
- *M* Final assembly, test and dispatch

TLC:
- *B* Accounting
- *B* Custom product design
- *B* Sales agency function

Global parent:
- *B* Technical & regulatory support

Sister companies within the global parent: (thin line)
- *M* Component manufacture

Independent partners: (double line)
- *M* Component manufacture
- *B* Technical & regulatory support
- *B* Marketing

Figure 1.
Summary of the network organisation adopted for the product incubator

Analysis of the proposal

It is said that the creation and building of core competencies is difficult, and that it is essential for management to list existing capabilities in order to identify missing links (Yusuf *et al.*, 1999). These, it is suggested, can then be in-sourced or acquired through alliance. At the incubator proposal stage, detailed analysis of the competencies likely to be needed for successful operation was carried out (Webster and Sugden, 2001a, b). This analysis formed part of the ongoing action research and it incorporated both internal and external (independent) perspectives. A number of dedicated meetings were held between the academic observer and the managing director over a period of several weeks to discuss competence and capability requirements for implementation of the proposal. As part of this process, the plan was examined in the light of nine factors said to contribute to the success of virtual enterprises (Christie and Levary, 1998). These factors relate to issues associated with customer focus, business partners, communication, technology, information, organisation, leadership and worker qualities. For each of these areas, existing competencies at TLCML were noted, and gaps that would need to be addressed were identified. Details of the analysis are summarised in columns two and three of Table I. Actions taken in order to address the competence gaps are discussed.

Actions taken in order to develop/acquire the necessary competencies

There follows an account of how TLCML has addressed each of the missing competencies identified through analysis and listed in column three of Table I. It is of additional interest that as a new or revised organisational form is implemented it is said that the development or acquisition of necessary competencies and skills is generally a gradual process as the organisation learns and adapts (e.g. Harland and Knight, 2001; Shepherd *et al.*, 2000). It should be noted that the company continues to monitor and review its competence portfolio as the implementation proceeds and as business develops.

*Product development skills and marketing expertise.*On the formation of TLCML, a number of directors and senior staff transferred from TLC. These included people with experience of the industry, products and technology and with expertise in product development and marketing and sales activity. Marketing/sales skills and knowledge were transferred with one of the founding directors who moved from a similar role in TLC and took responsibility for this activity. He soon established working links with independent commission-based marketing agents, who continue to provide remote support. Competencies in product development were also transferred at director level. These had been gained by assisting former licensees with activities such as re-designing prototypes for production, managing contract PCB design, designing and sourcing tooling, selecting subcontract PCB assemblers and managing pre-production/first years' manufacture. These competencies were initially restricted to the controller and were used immediately for product development in TLCML. There remained, however, an early need to develop expertise in other aspects of the product architecture. Specific motor and motor application skills were bought in as part of the motor facility acquisition. Additional technical skills and regulatory knowledge have been (and continue to be) accessed through a technical centre within the parent

Table I.
Contributory success factors for virtual organisations

Contributory factor	TLCML current competencies	TLCML required competencies
Focus on customer needs	Provision of high performance products at low cost with rapid response – to facilitate product differentiation for customers	Product development skills and marketing expertise
Effective choice of business partners	Existing local manufacturers for standard items (controllers); owned remote facility for non-standard items (motors); sister organisations within the parent for supply of some parts; sister organisation (TLC) for design, accounting and some sales functions	Supply system management skills to be developed with existing range of business partners in order to facilitate full-scale manufacturing activity
Existence of trust between partners	Already exists to some degree through historical relationships (prototyping) and through the parent company structure	Relationships within the supply system to be consolidated and developed through future joint operations
Effective communication and sound information engineering	High-technology company that has a proven track record of electronic communication with its parent and with its suppliers	
Use of appropriate technology	Computerised telephone system, voice-mail and e-mail; high levels of computer literacy, international video-conferencing facility	Development of operational systems for effective manufacturing and supply system management (e.g. ERP, EDI, e-commerce, Kanfax)
Protection of proprietary information	Established record of strategic protection of intellectual property rights	
Appropriate organisational structure	Current company structure derives from a professional organisation, based on flexible workforce and effective communication	Review of virtual manufacturing company structure as business develops. Roles and functions to be monitored and developed
New leadership methods	Experienced managers, but primarily with business/product development expertise	Need for additional leadership, managerial and administrative skills
Changed worker qualities	Experienced staff with competencies in manufacturing management, planning and control have been recruited	Majority of the remote workers will not be directly employed. Competencies in high-technology communication may need to be developed in some instances

Source: Christie and Levary (1998)

group and through an independent UK-based certification and approvals provider. Product design and development activity continues to be handled by a mix of internal engineering skills (including the recent transfer from TLC of a senior engineer as engineering director), outsourcing (mainly to TLC) and customer involvement.

*Supply system management.*This is an area in which TLC had only limited in-house experience. Supply management skills were initially bought in with the recruitment of an experienced manufacturing manager before the launch of TLCML. This facilitated the development of a strategic supplier reduction programme and operational systems for supply prior to manufacture. For several months during start-up he was able to evaluate suppliers. One of the criteria for selection (in addition to quality, delivery and price issues) was the extent to which they could supply multiple components and thus prevent the proliferation of suppliers. The role of purchasing for the motors and controllers was originally separated and shared between the recruited manufacturing manager and one of the founding directors. However, as soon as the income stream could support it, a procurement specialist was employed to co-ordinate purchasing for both components over both owned sites. A production manager and an electro-mechanical engineer at each site provide support for this function.

Relationships with suppliers to be consolidated and developed. As TLCML began manufacturing, many of the prototype component suppliers for TLC started to benefit from volume business. Similarly, pre-existing suppliers to the motor facility were retained and given steady volume requirements. A number of new suppliers were added, including some which already supplied to the global mass-manufacturing parent under price-favourable, high-volume supply deals. For these, TLCML has benefited from globally-negotiated cost advantages. Supplier development is an ongoing process and relationships continue to mature. TLCML staff regularly participate in "supplier days" and company visits through one of the company's major customers. Here, they work with their own tier – one suppliers, and with other suppliers to their customer on programmes of cost reduction, quality, design, and supply. With the recruitment of specialist purchasing expertise it is planned that further supplier development initiatives of this sort will be undertaken.

*Development of operational systems for effective manufacturing and supply system management.*The manufacturing manager recruited before company launch, played a pivotal role in the establishment of operational systems for effective manufacturing and supply system management. This included setting up practices and procedures for manufacturing support (e.g. operations planning, inventory control, purchasing) and for costing (including activity-based costing, invoicing, etc.). The software necessary to support these activities was scoped and specified. An ERP-based, fully integrated package was subsequently purchased. This is installed across both home sites with a data link to allow real-time data access from both. There are no direct IT links with any network partners. Upstream, the management of supply is implemented using conventional ordering/dispatching/communication methods such as telephone, fax and e-mail. This works well and integration of systems is not currently regarded as necessary for success. Looking downstream, there are currently two major customers – one has neither the wish nor the resources to integrate with TLCML's internal ERP system, and the other orders only very limited numbers of high-value products. In this situation there is little perceived benefit to either partner in integrating software systems. According to much of the theoretical discussion on virtual enterprises (and summarised earlier in the paper), IT links with network partners (both suppliers and customers) is a critical factor for success. The practice seen at TLCML contradicts this view. As discussed later in the paper, business success has been achieved through the implementation of a form of virtual manufacturing, without the need for IT system integration.

Review of virtual manufacturing company structure. In common with most company start-ups the organisational structure for TLCML continues to evolve as practical and business needs dictate. The initial structure was based around a professional and flexible workforce supported by effective communication. As business has grown the company structure has been monitored. The need for new functions has been identified and addressed by the modification and formalisation of existing roles and by the creation of new ones. The company has retained its agility and responsiveness by using principles of virtual manufacturing and by nurturing its culture of resource flexibility. It has a network of business partners from which it draws capability as necessary in order to meet its customers' needs. Review of structure is a component of agility and is a feature of the virtual approach to organisation. It continues to form a significant part of strategic management activity within TLCML. Continuing pressures on the company from the business environment and from its parent preclude complacency. It is recognised that continuing business success and even company survival depends on a corporate culture that embraces change. This has to date restricted the extent of employee resistance to change.

Need for additional leadership, managerial and administrative skills. As outlined, the managerial structure initially consisted largely of senior staff transferred from TLC and of recruited specialist staff. The two founding managing directors had between them a mix of industry experience, management qualification and leadership flair. The company's initial experience and skills base included competencies in the management of engineering and manufacturing activity and in industrial marketing. The company was additionally fortunate in having access to the supporting skill resources of its parent and sister companies. As business developed, additional skills were acquired through direct employment (e.g. for procurement and product development), and through recruitment of freelance specialists (e.g. for marketing and manufacturing support functions). A programme of employee development and training has been established in order to identify and address any emerging skill shortages. This has included, for example, the direct involvement of all manufacturing staff in a customer-led programme of value stream mapping. In order to achieve the high levels of flexibility needed for operations, it is important that staff, including those involved in direct manufacturing, are multi-skilled. As a result of the competence analysis, at the time of implementation, a need for additional leadership was suggested. However, successful company operation since implementation has developed the leadership skills of the transferred managers, and thus to date, the need to recruit additional leadership has been averted.

Development of competencies by remote workers. As part of the programme of employee development and training, all manufacturing staff employed by the company have been trained to use the ERP/manufacturing software. This enables them to undertake manufacturing support and administrative tasks, such as raising manufacturing orders, booking-in goods, and raising orders for consumables, etc. This includes staff based at the remote motor assembly site. Additionally, the home-based company product service engineer has been trained to use electronic mail in order to improve his effectiveness.

Current organisational and business situation at TLCML

In terms of business performance, TLCML has been operating independently of its sister and parent for more than two years. At the start of the paper it was asserted that a true virtual manufacturer has no in-house manufacturing capability at all. TLCML assembles both the motors and the controllers in-house. It additionally undertakes product test prior to dispatch. The scarcity of suppliers with the requisite skills for motor manufacture and the ready availability for purchase of the former licensee's motor facility, led to this activity also being carried out in-house, albeit remotely. A practical consideration that has influenced the company structure and strategy is the bulk and weight of the finished products and of the raw materials used for manufacture. Resulting high transportation costs preclude the use of geographically-distant manufacturers for much of the product-build, and realistically restrict network partners to those close to the existing manufacturing network. Thus, practical and business considerations have resulted in an organisational form that is not truly virtual.

However, manufacturing labour costs account for only 9 per cent of the cost of sales, while materials (with an annual spend of £1.5 million) represent 58 per cent – a split that is indicative of the importance placed on external sources of supply. If used as a measure of virtualness, the apportionment of direct costs at TLCML suggests that it is approaching the theoretical virtual business model. (An interesting, but separate, discussion that results from the work presented in this paper is the measurement of an organisation's virtuality (Sugden and Webster, 2002).)

As it continues to operate, the company is seeking to extend its virtuality in order that it can enter new markets and exit old ones, following market demand, without the burden of having to increase or decrease manufacturing facilities and resources. Measures to increase the virtual component of its operations have been identified, including the potential outsourcing of manufacturing processes from the remote motor production site, to leave only assembly of motors and controllers as internal functions. The company is actively investigating this possibility. The company is also considering using alternative manufacturing partners from within the parent company, and external to it. Without being articulated as such, the pursuance of virtuality by this company aligns with a strategy of seeking operational agility. This accords with the contemporary theoretical arguments put forward for the adoption of agile and virtual business systems.

The commercial success of the company can be measured by its rapid growth in sales during the two years of independent operation and by the fact of excellent profitability achieved in the second full year of trading. Sales in fiscal year 2000 amounted to £1.1 million which increased to £2.4 million in 2001 (an increase of 118 per cent). Future sales growth will depend on winning orders from new OEM customers and the introduction of new products with the existing OEM customer. The company expects sales to grow to £2.9 million in the third year of trading, an increase of 21 per cent, driven by new product introductions only. Further significant sales growth is expected in the fourth year of trading with the launch of a new product for a new OEM customer. In the first full year of trading, TLCML made an operating loss of £127,000 (11 per cent of sales) which became an operating profit in 2001 of £205,000 (8.4 per cent of sales). Operating profit for the third year of trading is expected to increase to £415,000 (14 per cent of sales). The sales and profitability figures for TLCML for fiscal years 2000 and 2001 are summarised in Figure 2.

Concluding theoretical analysis of the case study

The changing competitive environment requires organisations to review, and possibly change, their strategies in order to remain competitive (Davies and

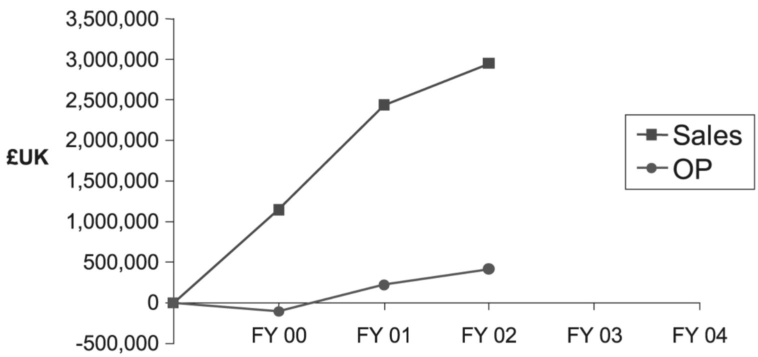


Figure 2.
Analysis of TLCML business performance

Kochhar, 2000; Barnes and Hunt, 2001, p. 139). Global competition, rapid technological change and escalating variety are seen as drivers of such change (Davies and Kochhar, 2000). There is, increasingly, conflict between having clear strategic intent to provide consistency for short-term action and stability for long-term planning and having strategic flexibility to facilitate the changing of strategies in response to new information, and business conditions (Petersen *et al.*, 2000; Hayes and Pisano, 1995). Operations strategies are fluid, transitory and will change over time (Lowson, 2002). Thus, in generating strategy to meet the objectives of protection of its technology, and control over its exploitation, a technology developer should plan to retain the ability to switch modes of operation. Changing business circumstances for TLCML in the 1990s, forced it to review its operations and business strategies. These included changes of company ownership and structure leading to reduced independence and business freedom, diminishing markets for the sale of the technology and the need for further investment in the technology development process. Aside from the links to a rapid technological change, these drivers differ from those suggested by Davies and Kochhar (2000).

The company chose to extend from an operations strategy of pure outward technology licensing to develop a second strategy of manufacture based on virtual principles. Such a move, necessitating the acquisition and/or development of new competencies can be seen in the light of Schonberger's (1996) recommendation for business success "as important as expansion and growth, *per se*, is growth of competencies. It's simply too risky in a turbulent world to depend again and again on the same resources, products and skills". The decision represented the establishment of a novel business stream which, like all new ventures, carried a risk of failure. Shepherd *et al.*(2000) note three types of novelty that contribute to the mortality risk of new ventures: novelty to the market (i.e. customers not knowing the organisation); novelty in production (i.e. lack of in-house knowledge and experience with necessary operations processes) and novelty to management (i.e. a lack of internal expertise in starting-up and running a business). These three dimensions of risk are reflected in the analysis framework for virtual businesses (Christie and Levary, 1998) that was used to analyse the company's competencies at the proposal stage.

Characteristics of virtual manufacturing and factors considered critical for its success were discussed from a theoretical perspective at the start of the paper. The case of TLCML can be seen to conform to these in some areas and to discord from them in others. As the company seeks to extend its virtuality, it aims to move into and out of markets more actively. This will allow it to configure temporary networks in response to specific business opportunities as they arise. It differs from much literature-based thinking in its use of IT for manufacturing management. Although the company has sophisticated communication technology and considerable IT expertise, it does not use advanced integrated software systems to network with customers, suppliers or subcontractors. In accord with the views of some authors (Lau and Wong, 2001, Katzy and Dissel, 2001), and with the practical experience of another virtual enterprise (Webster, 2001) business success, using the virtual model, for this company is not dependent on the use of sophisticated IT. Additionally, in line with the views of Katzy and Dissel (2001), not using ERP to integrate all manufacturing partners has not detracted from the operation of the system.

Summary and conclusions

This paper has presented details of an innovative company that has responded positively and successfully to challenges that it faced within its business environment. As part of a major strategic re-orientation, it has adopted a contemporary organisational structure for manufacturing and it has implemented this by the inventive marshalling and use of physical and human resources. The significance of this work has two dimensions. For the industrial community it provides an example of successful strategic transition. While not yet achieving total virtuality, the company has shown that moving towards the concept of the virtual manufacturing system is feasible. Further, it shows that this concept is not confined to the major well-resourced organisation, but with leadership, vision and drive, it can be implemented by the average small company. It additionally demonstrates the existence of a low-risk intermediate alternative to technology licensing and full-scale manufacturing for the exploitation of technology. For the academic community, it demonstrates how the popularised theoretical concept of virtual organisation can be implemented in practice. The process by which the necessary competencies were identified and acquired by a single organisation is of value in developing generic methodologies. Returning to the research questions that underpinned this work, the paper has shown that the adoption of the virtual manufacturing model can offer a commercially-viable operations strategy for the exploitation of product-related technology. It has additionally validated a theoretical framework of critical success factors for virtual businesses, by its use to analyse and identify the competencies and capabilities needed in a particular business situation.

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