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A Proposal for a Measurement Scale for Manufacturing Virtuality

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**A PROPOSAL FOR A MEASUREMENT SCALE
FOR MANUFACTURING VIRTUALITY**

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ABSTRACT

The paper presents a scale by which the extent of the virtuality of a manufacturing organisation can be measured. Literature review and analysis has been used to provide theoretical background on operations strategy and virtual manufacture. The conceptual measurement scale is presented and justified by reference to this theoretical review. The empirical component of this work includes presentation of case study descriptions of three companies manufacturing in the global electronic and electrical industrial sector. These companies, each having adopted different operations strategies, potentially represent the two extremes and the mid-point on the virtuality scale. Application of the scale to them is described, and the results obtained are shown to provide evidence of its validity. The paper concludes by discussing the generic significance of the work and by presenting future directions for the on-going research.

Keywords: virtual manufacture, virtuality, operations strategy

INTRODUCTION

Features of the 'New Economy' include increased emphasis on inter-enterprise collaboration within networked supply systems (Euroma 2002). Extending the notion of the networked value chain leads to the concept of the virtual organisation as the ultimate 'New Business' form. The extent of 'virtuality' of an organisation can be seen as a measure of how far it has embraced the concept of the networked value chain. This paper presents conceptual and empirical findings that contribute to the definition and measurement of virtuality as applied within the context of virtual manufacture. The objective measurement of the extent of virtuality of an organisation will facilitate the process of benchmarking against industry best practice. Additionally, the development of understanding of its virtuality, will assist an organisation in generating and implementing operations strategy that is responsive to global competitive pressures.

It is in the development of operations strategy that the structure of the manufacturing organisation is determined. This key decision is based around options relating to the amount of internal manufacturing capability that is used as opposed to the proportion of value-adding activity that is outsourced. Most definitions of virtual manufacture incorporate the notion of extensive outsourcing to suppliers and subcontractors in order to achieve a flexible, responsive network-based organisation. Linked to this is the idea of core competence, and the strategic orientation of an organisation around those competencies that provide competitive advantage within the New Economy. The concepts of strategic alliance and collaboration within networked value chains are commonly cited in the literature on virtual manufacture. Successful virtual organisations are able to marshal core competencies from a range of independent external agents through the strategic use of outsourcing mechanisms. The skills and expertise of all participating organisations contribute to the success of the networked value chain as a whole (e.g. Siquiera & Bremer 2000, Flores & Molina 2000, and Cunha et al 2000).

Based on the above, the degree to which an organisation makes use of external competencies could be argued to define its virtuality: as in-house competencies are increasingly marshalled in favour of independent supply, the extent of virtuality decreases. A continuum model by which the virtuality of an organisation may be measured can be envisaged. If such a model can incorporate

reflective measures that are based on objective, accessible company data it has the potential to be universally applicable. Research into the definition and measurement of virtuality is immature, and much work remains to be done. The work presented in this paper addresses these issues and thus makes a contribution to the research gaps identified.

OPERATIONS STRATEGY

The appropriate choice of operations strategy is key to the commercial success of any enterprise and is a critical issue for operations management. The changing competitive environment requires organisations to review, and possibly change, their strategies in order to remain competitive (Davies & Kochhar 2000, Barnes & Hunt 2001, p. 139). The founding empirical work on which this paper builds is based on the case of a company that reviewed and then changed its operations strategy in response to competitive pressures. Specifically it concerns the operations strategy options available to an organisation involved in new technology research and development (Webster & Sugden 2001a and b; case study 2 later in this paper). For companies of this sort, competitive advantage derives from the successful protection of the technology, and from an ability to effect rapid market penetration. Alternative operations strategies by which this can be achieved exist, with traditional strategies able to be modelled conceptually on a continuum between two extremes. Each of these involves the development and use of altogether different operations capabilities and competencies.

At one extreme is the option of outward technology licensing, in which the technology originator retains its focus on design and development competence. Manufacture is undertaken independently by organisations that buy the licensing rights. At the other extreme is the establishment, by the technology originator, of comprehensive in-house manufacturing facilities in order to build products designed around the protected technology. 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 in supporting resources. Virtual manufacture, described below, offers a compromise that represents a potential mid-point on the continuum.

VIRTUAL MANUFACTURE

"In contemporary business environments, organizations are faced with tremendous competitive pressures. The global economy, combined with issues of rapid technological change and the increased power of consumers, places huge demands on firms to remain responsive and adaptable (Drucker, 1995). Globally, common influences include rapid political changes, regional trade agreements, low labour costs in some countries and frequent and significant changes in markets. In addition, there are trends towards the changing nature of the workforce (older, better educated and more independent)..... Furthermore, technology is playing an increasingly important role in business in this environment; increased innovation and new technologies are providing vast improvements in cost-performance and an important impetus to strategy, rendering existing technologies and infrastructures obsolete..... The 'virtual organization' may provide the much sought after flexible and synergistic business model for this Millennium." (Barnes & Hunt, 2001, p. 139).

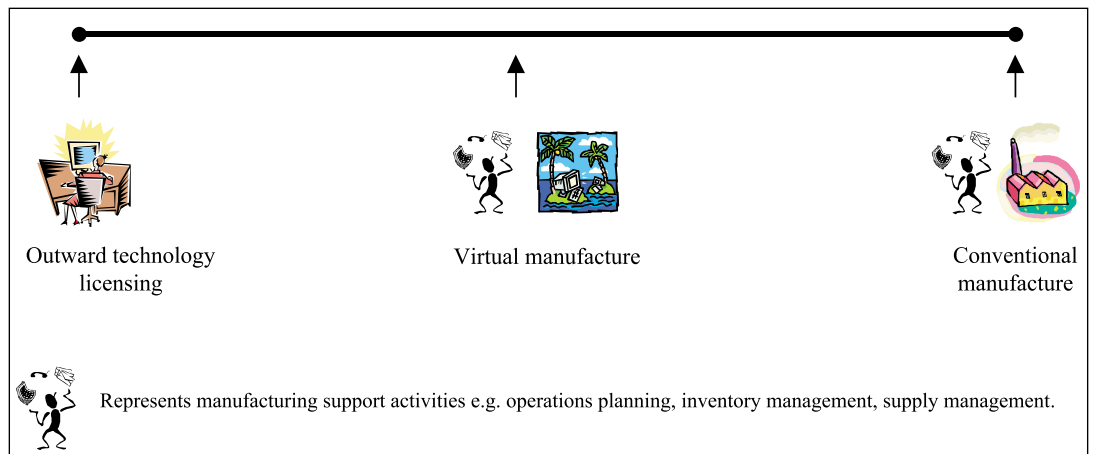
For any organisation, in order to keep investment costs under control and to restrict uncertainties about the manufacturing capabilities of the company, a manufacturing strategy based on a disaggregated or extended enterprise has been suggested (Banerjee 2000). This strategic architecture is increasingly linked to the concept of virtual manufacture which presents itself as an alternative business model (e.g. Christie & Levary (1998), Mezgar & Kovacs (1997), Reid et al (1996a and 1996b), Schumacher et al (1996), Camarinho-Matos et al (1998) and Introna 2001). This involves the creation of temporary 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.

The option of establishing a virtual manufacturing system can thus be seen to augment the range of strategic choices traditionally available to an organisation for the exploitation of its technology. By the same arguments, as an operations strategy, it additionally offers many advantages to organisations that have traditionally invested in comprehensive in-house manufacturing capability and resources. Its innate agility and fluidity facilitates rapid market penetration. The virtual manufacture approach represents an intermediate position on the operations strategy continuum described above and requires a compromise in terms of skills and competencies. The organisation is required to organise, manage and plan manufacture but it is not required to develop specific manufacturing process skills or to invest in manufacturing resources.

The conceptual model of operations strategies described above is summarised in figure 1. For technology licensing, competencies remain focused on design and development. For conventional manufacture competencies in establishing and managing a manufacturing plant are required in addition to those that support manufacturing (such as operations planning, supply management etc). For virtual manufacture, competencies in only the manufacturing support activities need be developed. Potentially, even these may be outsourced.

FIGURE 1. STRATEGY OPTIONS FOR THE EXPLOITATION OF TECHNOLOGY



Virtuality measurement scale

The concept of 'virtuality' per se has little coverage in the literature on virtual organisation, which tends additionally to adopt a highly conceptual stance. Detailed pragmatic definition and description is uncommon. Sieber (2001), however, presents a functional view of a virtual enterprise in which he discusses the property of 'virtuality' defined, by his reference to Venkatraman & Henderson (1994), as:

"... The ability of the organization to consistently obtain and coordinate critical competencies through its design of value-adding business processes and governance mechanisms involving external and internal constituency to deliver differential, superior value in the marketplace" (Sieber 2001, p. 251).

A more simple definition, ascribed to Sieber, but offered by Bremer et al (2001, p. 213) is:

"virtuality can be defined as the ability of an enterprise to order customers a complete product or service, with the enterprise itself having only a few proprietary competencies".

The concept of virtuality has a limited theoretical base. One of the aims of this work is to disaggregate the concept into constituent components, and thereby to increase understanding of its key features. It is further suggested that the constituent components, when combined in an appropriate way, can serve to measure the extent of virtuality of an organisation.

Existing now, only as a rather esoteric concept, the pragmatic measurement of virtuality would bring many benefits. It would serve to assist with the classification of organisations and with benchmarking between them. It would also provide guidance and direction for organisations

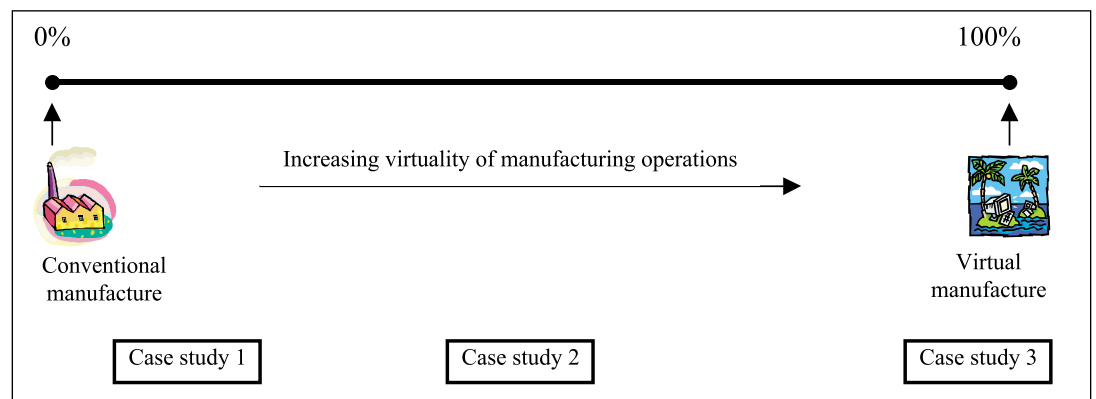
in determining and delivering operations strategy changes. In preliminary investigations however, literature search has revealed a dearth of work on the subject. In a related area, a system has been proposed for the measurement of another popularly-cited, but vaguely-defined concept - that of the 'leanness' of an organisation. This is offered by the Lean Enterprise Institute (LEI 2002) and is based on the calculation of inventory turns (annual sales divided by the amount of inventory on hand [spot, year-end or average] to support this level of sales). Although considering a different aspect of organisation, this approach is similarly attempting to capture and measure an intangible concept.

In this work, the proposed virtuality scale relates to the operations strategy continuum presented in figure 1, but applies only to the centre-to-right section between conventional and virtual manufacture. Figure 2 summarises the concept. The scale is supported by two dimensions based on financial and non-financial factors. It is suggested that the two dimensions complement each other in measuring and plotting the virtuality of individual organisations. The financial aspects provide hard, quantitative data to indicate virtuality and to enable positioning on the scale. The non-financial aspects provide corroborative qualitative information to support this positioning. The components of the scale are discussed below, followed by description of its application in three companies that operate in the same industrial sector, but with differing operations strategies.

Financial dimension

This dimension of the scale is based on the use of public-domain financial company information, from which selected data can be interpreted in order to identify indicators of virtuality. Four specific financial measurement indicators were chosen on the basis of being readily calculable from this information and expected to demonstrate levels of virtuality:

FIGURE 2. MEASUREMENT SCALE FOR MANUFACTURING VIRTUALITY



- Return on Capital Employed (ROCE)
- Sales per employee
- Profit per employee
- Ratio of investment in stock and work in progress (WIP) to sales

Return on Capital Employed (ROCE) would be expected to be high for virtual organisations and to decrease along the scale as more capital is employed in establishing the functions of conventional manufacturing such as manufacturing facilities and supporting administration. As virtual organisations have few direct employees, their ratios of sales per employee and profit per employee would be expected to be greater than those for more traditional manufacturing organisations. A decrease in these ratios would be expected in moving along the scale between virtual and conventional manufacture. Investment in stock and work in progress (WIP) as a percentage of sales would be expected to be lowest for virtual organisations because physical stocks would be more likely to be located with outside contractors than kept in house. Moving along the scale towards conventional manufacture should see an increase in this ratio, as the functions that require the holding of stock and WIP are handled internally. In support of using the last 3 of these ratios, Presley et al (2001, p. 145) state:

"It is expected that the VE (virtual enterprise) will possess almost no employees or inventoried resources".

Non-financial dimension

Non-financial aspects of an organisation provide qualitative evidence to indicate virtuality. There is some limited support from the literature for this aspect of virtuality measurement. For example, Burn & Barnett (1999) discuss "degrees of virtuality", and suggest factors that may constrain these. These include supply management issues relating to communication methods and relationship types. Sieber (2001) defines three evolutionary stages of virtual organisations that relate to resources, processes and markets. He goes on to propose a form of organisational mapping of virtuality based around these and the evolutionary stages of the development of the virtual organisation. Recognising their innate differences from traditional organisational forms, Katzy & Dissel (2001) emphasise the need to change planning and control systems for virtual enterprises. These, they say, include MRP and ERP, i.e. systems that incorporate operations management functions. Whilst efficient in stable

non-virtual environments, they can hinder the responsiveness and agility that is necessary in a virtual environment. The increased importance of planning, control and logistics activities to the success of virtual enterprises is also stressed by Soares et al (2000). Informed by this work, it is held here, that issues such as the nature of operations management, the extent of outsourcing, the distribution of internal competencies and the form of value chain relationships contribute to the development of an understanding of an organisation's virtuality.

EMPIRICAL VALIDATION OF THE MEASUREMENT SCALE

The measurement scale model has been validated initially on three organisations within the global electrical / electronic industrial sector. In order to collect empirical evidence about the non-financial issues from the companies, a structured interview protocol has been developed (included here as appendix A). In this, questions are grouped under the headings of general information, financial information, supply and subcontract arrangements, and operations management. For the operations management area, standard functions were identified from a functional specification for generic manufacturing planning and control systems (Howard et al 1998). The protocol was sent to the collaborating companies a few days prior to a pre-arranged face-to-face or telephone conference interview. During the interview, answers to the protocol were sought and recorded using audio-tape. For the financial dimension of the scale, source data has been obtained from published company accounts via the Financial Analysis Made Easy database (FAME 2002). This was used to calculate the four financial parameters described above over a five year period.

The information collected has been used to develop the following brief case studies of the three companies. For reasons of confidentiality, the identities of the organisations described in the cases have not been stated.

Case study 1

The company in this case produces analogue switching power supplies, principally for the computing, telecommunications, networking and cell-phone industries. The power supplies are used in products such as computers, battery chargers, adaptors and mobile telephones. The majority of the products are produced in very high volumes for original equipment manufacturers (OEMs) in the computing and electronic industries. Products

for the computer networking aspect of the business are produced in lower volumes but attract higher margins. The company is part of a large global organisation, and has its corporate headquarters in California, USA. The company is a major employer of engineers worldwide and, in particular, of analogue design engineers. The engineering functions are handled from sites operating in the USA, Hong Kong, China and the Philippines. The company has 3 major manufacturing sites - one in the Philippines and two in Mainland China. Globally, the company employs approximately 20 000 people, the majority of these being direct manufacturing labour employed at the sites in Asia.

The organisation has a 'traditional' vertically integrated structure with all functions carried out internally. There is no outsourcing of non-manufacturing activity, with only minimal use of subcontract manufacture. Examples are the occasional subcontracting of printed circuit board assembly and test when internal facilities are overloaded and the outsourcing of specialised processes e.g. for plastic components. All purchasing and planning activity for manufacture is carried out in Asia, and employs approximately 100 staff. Classic purchasing activity (placing orders etc) is carried out largely within the manufacturing plants in the Philippines and China. More strategic procurement activities, such as the development of sourcing strategies and decisions on multiple sourcing, are handled from a "side-organisation" in Hong Kong under the remit of the global parent company.

Operations management systems and procedures are geared to high volume manufacture, for which control over operations is critical. The approach is highly structured and hierarchical. A centralised MRP approach is used for all aspects of business planning in the company. It is in the process of updating a legacy MRP system by implementation of the Manugistics MRPII software suite. Primary data accuracy (e.g. bills of materials and inventory records) is high and systems for basic data maintenance are effective. Product life cycles are short (typically 6 to 12 months) and demand forecasting is problematic. The software system is not used to predict future demand levels, but a more traditional sales forecasting approach is used. This part of the planning process is challenging because customers typically fail to be precise in forecasting their future requirements. After a degree of internal modification, customer demand is rolled directly forward to the MRPII system as the definitive statement for production.

Thus the key difficulty with using the MRPII system is the "top input", i.e. the details of predicted future demand. This creates knock-on problems for operations planning, particularly for aggregate planning and the creation of the master production schedule. Operations scheduling and day-to-day planning of works and purchase orders is based on the output of the MRPII system. Suppliers are sent weekly rolling "vendor action reports" by EDI or Email, as appropriate. These give details of firm requirements together with forecasts of anticipated demand for the next 12 months. MRP and purchasing are handled centrally for all three manufacturing units. Most procurement is to weekly schedules rather than to individual purchase orders. For approximately 75% of company purchases, suppliers deliver product to a physical 'hub' or warehouse. This can, for example, be owned by them or by an independent agent. Ownership of the inventory at the hub remains with the supplier, until the case company 'pulls' stock daily to meet immediate manufacturing demand at the three sites. Each week, suppliers are given details of what is planned for pull that week, although this plan is subject to daily change.

The products have a high material content (approximately 60% of revenue is spent on incoming materials) whilst, being based in Asia, direct labour costs are relatively low (estimated at approximately 10% of revenue). With such a significant spend on components and raw materials, efficient materials supply arrangements are critical for the success of operations, and there is high reliance on purchasing and associated activities. Quality is of primary importance in choosing suppliers but there is a significant focus thereafter on price and on flexibility. Suppliers are required to be "nimble", particularly in the light of the relatively short product life cycles for most products. The company operates a multi-sourcing policy and aims for 2 to 4 capable suppliers for all parts. Ideally, for each item, one vendor would supply approximately 60% of the call with the remaining suppliers sharing the balance. Relationships with suppliers are contractual and are described as strong and medium-term. Switching between suppliers, in order to achieve more favourable contractual terms of supply, is common. Communication with at least 85% of company suppliers is based on semi-annual, face-to-face commercial and engineering meetings. Pricing and other commercial terms of supply are negotiated at these meetings with senior supplier representatives. Routine communication uses EDI, where supplier systems are compatible. This

applies to many of the suppliers and is increasing. Email / telephone is used for others, particularly for suppliers in Asia, where the adoption of electronic technology is less widespread.

Case study 2

As mentioned earlier, this company changed from a strategy of technology licensing to one of virtual manufacture. Longitudinal study of the development, justification and implementation of this decision formed the basis on which the work presented in this paper was built. In the preliminary study, literature search and review was used to define, describe and discuss the strategies of technology licensing and virtual manufacture. Thereafter, empirical evidence, generated through the development of the longitudinal case study was collected (Webster & Sugden 2001a and b).

The company is closely related to a small UK-based company that was taken over in the early 1990s by a major global corporation. The original company has a proven record of innovation and technology development in the field of electrical-drives and motors, and had always used a strategy of outward technology licensing to generate business success. In the late 1990s, commercial pressures and an increasing awareness of the potential offered by virtual manufacture encouraged the company to undertake a comprehensive review of this strategy. The feasibility of the use of a virtual manufacturing system as an alternative to technology licensing for the exploitation of the company's product related technology was explored. The virtual manufacturing option was considered in relation to the case company and a proposal for its adoption was developed. The operational characteristics of the proposal were considered in relation to the existing capabilities and competencies of the company, and the changes that would be required in this respect were noted. A manufacturing company was created as a result, which completed its second full year of trading in September 2001. As implementation of the virtual manufacturing strategy began, modification of the original concept of virtuality occurred, and practical and business considerations have resulted in a current organisational form that is not truly virtual (Webster & Sugden 2002).

The company produces variable speed motors and controllers for industrial products including air compressors and laboratory centrifuges. Its principal customers are industrial OEMs in the UK and USA, and industrial end users in the UK. Annual volumes of production are approximately

500 each of motors and controllers. The company has two sites in Yorkshire, UK. These are located 40 miles apart. The first site houses the administrative offices and the electronics manufacturing unit where the controllers are assembled. The other is the motor manufacturing facility. The company, with 20 employees, is wholly owned by the global, US-based multinational and remains tied to its sister company that is co-located at the first site. The two companies share staff and physical resources. The company outsources many business activities, and all production apart from assembly and test. Thus, manufacture is achieved by a combination of internal and external supply. IT support and plant maintenance are provided by outside contractors. Certification for manufacturing some products is organised by a consultant through external agencies. Product development and design is outsourced to the sister company, and the HR function is provided by a combination of resources from the sister company and the corporate headquarters in the USA.

A finished product consists of a motor coupled to an electronic controller. Product life cycles are typically measured in years. However, a continuous process of design change is required in order to implement cost reductions and to replace obsolete components. Final assembly and test of both the motors and the controllers is undertaken at the two internal sites, but the major components for each are manufactured by external companies. This means that the company has considerable involvement in the management of supply and subcontract arrangements. For this activity a procurement specialist is employed who is supported by the managing director, the head of engineering and the electronics production manager.

Operations are managed hierarchically. Aggregate planning is handled by the managing director, financial controller and production managers using simple spreadsheets and monthly / quarterly forecasts. Material requirements planning is handled in a similar way by the production managers and procurement specialist. Typically, customers provide weekly forecasts that give expected Kanban requirements for both the short term (next week) and the longer term (following month). The accuracy of these forecasts is not good - actual Kanban call-offs do not reflect forecast demand. As a result, historical data is actually used for aggregate and materials planning. Operations scheduling for internal work is achieved using a Kanban system. Subcontractor

scheduling involves the use of a mixture of Kanban (by fax) and weekly delivery schedules to quarterly orders. Supplied parts are brought in through faxed orders and Kanban (by fax). Detailed planning of purchased and internal parts is supported by the use of the Winman software system for material requirements planning.

Effective supply and subcontract arrangements are critical for the success of operations in this company. Although important, the traditional factors of price and delivery are less significant in the initial selection of external partners than quality and capability. Virtually all materials are single sourced, and switching to new suppliers is not common. The company's relationships with suppliers and subcontractors are described as long-term and cooperative. They are maintained by telephone and personal contact and supported on a day-to-day basis by fax, email and telephone.

2002 financial figures for the company show that manufacturing labour costs account for only 9% of the cost of sales whilst materials (with an annual spend of £1.5M) represent 58% - a split that is indicative of the importance placed on external sources of supply. As the company has continued to operate, the organisational structure has been reviewed and measures to increase the virtual component of its operations identified. These include 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. It can be seen that the company currently operates with a manufacturing strategy somewhere between conventional and virtual manufacture. The more precise understanding and measurement of its virtuality was felt to be necessary in order to assess the success of the strategy and to inform future strategic direction. This need led to the current work on the development of a virtuality scale with the potential for positioning organisations on it.

Case study 3

The company in this case is part of a network of manufacturers described by Webster (2001). It produces tier 2 automotive electronic controls, measurement, instrumentation and general electronic products. Its principal customers are major OEMs in the automotive and chemical industries. It also supplies products to smaller companies in these markets through an intermediary marketing organisation. The company currently has two direct employees, both

directors of the company, and each based at their homes in different sites in Cumbria, UK. One is responsible primarily for sales and marketing activities and the other for design, procurement and production-related functions. All engineering and product development work including hardware design, software design and testing is outsourced. All logistics, distribution and IT support is outsourced to external agents, as are some aspects of sales and marketing.

Manufacturing is carried out entirely by external organisations in a number of different global locations. The delivery of finished products to customers is organised internally, and usually occurs direct from manufacturer to customer without the virtual company taking physical ownership. Occasionally, warehousing owned by manufacturing partners is used to store products supplied by other partners.

Operations are managed largely without the use of formal systems and methodologies. Aggregate planning, master production scheduling and materials management are undertaken by the production director. His knowledge and experience of these areas is supported by the use of spreadsheet software to assist with some aspects. There is no use of materials requirements planning software. As all manufacture is outsourced, considerable reliance is placed on suppliers and subcontractors who work with the production director on the preparation of detailed production plans to meet required delivery dates. Some of the raw materials and components (e.g. integrated circuits and packaging) are bought by the company and then free-issued to suppliers. In some cases the company takes physical ownership of these components; in others, the stock is delivered directly to manufacturing partners. As the directors operate from home, the storage capacity is extremely limited and this restricts the extent to which the company can take direct ownership of tangible items. For other raw materials, particularly for high volume work and remote manufacturing (e.g. in China), the company does not take physical ownership. It organises purchase and delivery direct to the manufacturing partner. For raw materials, the processes associated with requirements generation, acquisition and issue are handled internally. The distribution of raw materials and finished goods is outsourced, but its co-ordination between suppliers, manufacturers and customers is organised internally. Production activity is regularly and closely monitored by the production director.

The success of this business is dependent on the appropriate choice of business opportunity and on the achievement of effective and efficient operations. Selection of business opportunities is based usually on them having an association with protected technology and the potential for high profit margins. This has resulted in a relatively wide range of diverse products and markets being addressed by the company. The achievement of high performance operations has been supported by the development of close, long-term, loyal relationships with business partners and suppliers. Commitment to all business partners is described as "project by project" rather than "minute by minute". This means that instead of directly employing staff, the company retains the flexibility to switch between partners. It is able to marshal the most appropriate skill and resource set for each business opportunity and project. Business relationships are, in many cases, geographically remote. They are supported by fully specified and detailed contracts, but are based on mutual trust and understanding. Although price is an issue in selecting suppliers, of far greater importance are capability, reliability and quality. With few internal resources, the company has to be able to rely on the performance of its business partners. Personal contact and telephone communication are important in sustaining relationships. Frequent, operational contact is maintained by Email, fax, and telephone. There are no direct computer links with any external organisation, and none are planned. Electronic integration is not used for the exchange of information between the company and any of its partners.

Summary of the case studies

The descriptions of these three organisations, demonstrate how, although the product types are similar, the manufacturing strategy of each differs. The extent to which they make use of in-house manufacturing capability varies considerably. Company 3 (virtual) operates with no in-house

capability, company 1 (conventional) with almost total in-house manufacture, assembly and test, and case 2 (semi-virtual) operates at a mid-point between. The different approaches taken to operations and supply management reflect the strategy differences. Application of the more objective virtuality measurement system using financial indicators provides quantitative measures that should yet more clearly reflect these differences. As mentioned earlier, financial source data was obtained via the Financial Analysis Made Easy database (FAME 2002). Details of the data used is included in appendix B. Relevant source data for cases 1 and 3 is available for a number of years, and an average over the most recent five-year period has been calculated. The calculations for case 2 are based on fiscal year 2001, as the company has only been operating for two years. During the start-up year the figures were of an exceptional nature and have been discounted in this work. The results of the calculation of the four financial indicators on the three case studies are tabulated in table 1.

All four indicators follow the trend predicted from the theory suggested in this work. The average ROCE figures show a 10:1 difference from the virtual to the conventional, with the semi-virtual lying in between. The average sales per employee ratios exhibit a 9:1 variation from virtual to conventional with the semi-virtual lying midway. The average profit per employee for the virtual case is more than 30 times that of the conventional manufacturer with the semi-virtual lying in between. The average stock and WIP as a percentage of sales demonstrates a 4:1 variation from virtual to conventional, again with the semi-virtual in between. In addition to the comparison of the five-year average values the results also show consistent corroboration of the theory on a year-by-year basis. These results suggest that these factors may be used as part of a scaling system to measure the virtuality of an organisation.

TABLE 1. CALCULATION AND COMPARISON OF VIRTUALITY MEASURES FOR CASE COMPANIES

Virtuality measure	Case 1 (conventional)						Case 2 (semi-virtual)	Case 3 (virtual)					
	5 yr ave.	2000	1999	1998	1997	1996	2001	5 yr ave.	2000	1999	1998	1997	1996
ROCE (%)	17	20	8.0	8.6	23.5	24.1	92.3	171	31	57	66	168	532
Sales/employee (£k)	31	43	26	27	29	30	153	299	99	85	284	411	619
Profit/employee (£k)	2	3	1	1	3	3	13	62	11	26	51	111	109
Stock & WIP /sales (%)	16.5	16.2	19.6	20.9	14.1	11.7	11.7	4.3	4.0	5.9	2.3	4.7	4.4

In this initial investigation no attempt has been made to isolate other factors that may influence the results. Differences in the level of sales between the organisations or differences in geographic location may, for example, contribute to differences in the calculated data. Further research, taking a larger sample of companies, is needed. This should include work to isolate the factors that may have additionally influenced the results of this study.

Based on the results of the financial analysis and on the qualitative accounts of the operations of each, the positions of the 3 companies on the virtuality measurement scale have been approximated in figure 2.

CONCLUSIONS

The development of a measurement scale for virtuality is of benefit for a number of reasons. It provides a quantitative, objective measure that offers organisations the ability to classify their operations strategies and to benchmark against industry best practice. It also offers an empirical basis on which organisations can base strategy decisions relating to the most appropriate form of organisational structure for manufacture. Further, by incorporating and combining a number of component measures, it can be used to provide guidance on future direction for organisations that aim to change the extent of their virtuality in line with changing manufacturing strategy. Movement or change in any of the identified dimensions will contribute to a change in virtuality.

This paper has presented preliminary work on the development of a scale for measuring manufacturing virtuality. The scale has been piloted on three companies and the underlying principles have been validated. The scale now requires refinement. Further research is needed to isolate the key factors that truly indicate virtuality from those that reflect other, unrelated issues. By incorporating a means of eliminating extraneous data the applicability of the measurement scale will be strengthened. Once this stage of work has been completed, the intention is to collect more empirical data by the application of the scale in different manufacturing environments. Ultimately, using the measurement process, it should be possible to generate generic findings about operations strategy and virtual manufacture in different operations environments.

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APPENDIX A – INTERVIEW PROTOCOL
VIRTUALITY MEASUREMENT: INTERVIEW PROTOCOL

SECTION A: General information

1. Please state the principal products produced by your company.
2. Please indicate how these products are used, and who your principal customers are.
3. What is the physical organisation of your company (e.g. number and location of sites)?
4. What is the overall organisational structure of your company? Please include here the total number of employees, links to parent and sister companies and functional divisions within your own company.
5. Please describe the organisation within the manufacturing section of the company, i.e. the structure, and number of employees within different functions. Please include both direct manufacturing activity and all supporting activities such as planning, materials management, logistics, quality, warehousing, etc.
6. Please describe the organisation within the materials acquisition section of the company, i.e. the structure and number of employees involved in purchasing, supply chain management, supplier initiatives etc.
7. Do you outsource any non-direct manufacturing activities such as product design, IT etc? If so, please give details.
8. Do you outsource (subcontract) any activities within the manufacture of your products? (*Outsourcing of manufacture refers to the use of an external organisation for part or all of the manufacture of any of your products, to a specification provided by you. External organisations include those with which you are linked through common ownership*).

SECTION B: Financial information

9. Please provide broad details of the cost breakdown of typical product(s)... or of the cost of sales?, i.e. % direct labour, % materials, % non-direct labour, % overhead.
10. Does the material component of a typical product, include both supplied and subcontracted parts, and if so, what is the % cost of the supplied and subcontracted parts?
11. If your company is small or medium sized (as defined by the Companies Act), please provide the following additional information:

- turnover
- stock
- WIP
- ROCE
- number of employees

SECTION C: Supply and subcontract arrangements

12. Do you use subcontractors for the entire manufacture and/or assembly of all of your products?
13. Do you use subcontractors for the entire manufacture or assembly of one or more of your products?
14. Do you use subcontractors for part of the manufacture of all or some of your products?
15. How would you describe your relationships with key suppliers/subcontractors to your organisation (examples of the types of words you might like to use here include: close, long-term, co-operative, arms-length, adversarial, contract-based)?
16. Please list the factors that are most important to your organisation in choosing to work with particular suppliers/subcontractors (examples might include: price, quality, delivery, technical skills, capacity, loyalty).
17. Please describe how you usually communicate with your suppliers and subcontractors (this should include frequency, content and means of communication [telephone, personal contact, mail, Email, EDI etc]).

SECTION D: Operations management

18. Distinguishing between internal and external activities as appropriate, please describe how, and by whom, the following operations management activities are carried out:
 - Rough cut resource planning
 - Master production scheduling
 - Planning of materials requirements
 - Production planning
 - Internal shop loading and operations scheduling
 - External operations scheduling, e.g. scheduling work onto subcontractors
 - Purchasing of supplied components and materials
 - Progress monitoring - internal and external
 - Manufacturing control and day-to-day prioritising of operations

APPENDIX B - SOURCE FINANCIAL DATA9

	Virtual 5year ave	2000	1999	1998	1997	1996	Semi Virtual 2001	Conventional 5year ave	2000	1999	1998	1997	1996
ROCE (%)	171%	31.4%	56.8%	66.2%	168.2%	531.7%	92.3%	17%	19.9%	8.0%	8.6%	23.5%	24.1%
Sales/employee (£k)	299	99	85	284	411	619	153	31	43	26	27	29	30
Profit/employee (£k)	62	11	26	51	111	109	13	2	3	1	1	3	3
Stock&WIP (%sales)	4.3%	4.0%	5.9%	2.3%	4.7%	4.4%	11.7%	16.5%	16.2%	19.6%	20.9%	14.1%	11.7%
Profit before Tax (£K)		32	79	102	222	218	205		50530	14496	14801	37162	33905
Total Assets less liabilities (£k)		102	139	154	132	41	222		253296	181990	171689	157946	140395
Number of employees		3	3	2	2	2	16		16841	16444	14878	13299	13128
Sales (£k)	636	297	254	567	822	1238	2447	465181	719417	426772	402511	386593	390611
Stock&WIP (£k)	27	12	15	13	39	54	287	76841	116341	83626	84110	54541	45586

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