Manufacturing in the World: Where Next?

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Abstract

Purpose – The past three decades have seen the transformation of manufacturing involving its global dispersion and fragmentation. However, a number of recent developments appear to suggest that manufacturing may be entering a new era of flux that will impact the configuration of production around the globe. This paper addresses the major emerging themes that may shape this configuration and concludes that most of them are still in their initial stages and are not likely to create a radical shift in the next few years in how manufacturing is configured around the world. These themes were presented in a Special Session on "Manufacturing in the World – Where Next?" at the 2013 EurOMA Conference in Dublin, Ireland.

Design/methodology/approach –The paper provides a series of perspectives on some key considerations pertaining to the future of manufacturing. An evaluation of their likely impact is offered and insights for the future of manufacturing are presented.

Findings, Linkage & Logic The importance of a focus on the extended manufacturing network is established. The need for customer engagement and a forward looking approach that extends to the immediate customer and beyond emerges as a consistent feature across the different perspectives presented in the paper. There is both the potential and need for the adoption of innovative business models on the part of manufacturers.

Originality/value - The paper presents in-depth perspectives from scholars in the field of manufacturing on the changing landscape of manufacturing. These perspectives culminate in a series of insights on the future of global manufacturing that inform future research agendas and help practitioners in formulating their manufacturing strategies.

Keywords Global Manufacturing, Operations Management, Sustainable Manufacturing, Re-shoring, Additive Manufacturing

Paper type Viewpoint

1. Introduction

The intensified off-shoring and outsourcing strategies in recent decades have transformed the global manufacturing landscape dramatically. From 1970 to 2010, the share of global manufacturing value added for the G7 nations dropped from 71 to 46 percent, taken up by the emerging countries, particularly China (Baldwin and Lopez-Gonzalez, 2014). This trend has been accompanied by increasing fragmentation of global supply chains, to the point that it has made it difficult to determine exactly where many products are made. They are best described to be "made in the world," a notion introduced some time ago (Ferdows, 1997a) but gaining greater currency since the launch of the "Made in the World" initiative by the World Trade Organisation in 2011 (WTO, 2011).

More recently, the idea of "re-shoring" (or "back-shoring" or "near-shoring")—i.e., bringing production closer to the company's home base or to its major markets--often combined with in-sourcing--has been receiving attention (Sirkin et al, 2011, PwC, 2014). There is a fresh recognition of the benefits of co-location of design and manufacturing functions and close proximity of factories to markets they serve (Pisano and Shih, 2012 a, 2012 b). Correspondingly, a substantial number of multinational manufacturers in developed countries are reported to be considering moving production from suppliers in far-away regions to closer ones or to their own factories (George et al, 2014). For example, in a recent survey, 21% of US-based manufacturers said that they were moving production back to the US or planning to do so (Boston Consulting Group, 2013). However, this trend is still in its infancy and the number of cases that have actually "re-shored" production is still small (see, for example, the data on German companies in Section 3 in this paper). If this trend gains momentum, it can herald a new pattern in global manufacturing and possibly a manufacturing renaissance in some of the economies that have been experiencing a hollowing out of manufacturing in the last few decades. Nonetheless other considerations, such as opportunities for tax arbitrage, proximity to market, access to special skills and talents, and other forms of arbitrage, are likely to continue to be key inputs to the location decision. The current proposals around changes in the taxation of corporate profits (OECD, 2013) introduce yet another element of flux into that decision.

Other trends are also shaping the future of global manufacturing. There is a growing move towards an "end-to end" approach and the strategy of so called "servitization" of manufacturing (Lightfoot et al, 2012). Xerox (selling photocopies and not just photocopiers), Rolls Royce (selling hours of operations of jet engines), IBM (adding maintenance service to sale of its hardware) are well-known examples. In recent years an increasing number of manufacturers have moved into this area: BAE Systems now supplies “outcome based” contracts to the Department of Defence in the UK; Castrol Lubricants offers sensing and diagnostic services in addition to supplying lubricant to its marine customers and there are more examples described in Section 2 of the paper.

Another trend is the increasing pressure from various stakeholders in the developed and developing economies to adopt sustainable practices. (e.g., Gladwin and Welles, 1976; Porter and Kramer, 2006; Waddock et al., 2002). Stakeholders are asking multinational manufacturers for both environmentally friendly and socially compatible policies across their entire global networks, including subsidiaries and suppliers (e.g., Bansal and Roth, 2000; Waddock et al., 2002). This affects not only how and where they produce, but *how they recover their waste and manage reverse logistics* (Nguyen et al., 2014). The effects of greening on configuration of global manufacturing patterns are already visible in some industries. For example, Intel has reduced its global energy bill by $111 million since 2008 as a result of $59 million of investments in sustainability projects worldwide (Ives, 2014).

Yet another trend is the accelerated introduction of several new vibrant technologies. They include additive manufacturing, nanomaterials, new generation of robotics (which are capable of sensing their environments) and use of “internet of things” in factories (where equipment communicate and coordinate their operations). These technologies have the potential, and some have already started, to change the traditional production methods for many products with profound implications for how and where in the world they are manufactured.

With such a variety of developments influencing global manufacturing today, a discussion of the likely future trajectories -including spatial, technological and operational--is both timely and necessary. These developments prompted the convening of a special panel session[1] at the European Operations Management Association 2013 conference to identify the critical factors impinging on manufacturing and to assess their impact on the future of production and of supply chains in the world. This was an ambitious agenda and the purpose of this paper is to capture, to explore and to integrate the key insights from this session.

[1] The session was held at the EurOMA 2013 Conference in Dublin in June, 2013. The title for the session was “Manufacturing in the World – Where next?” with Louis Brennan as Convener and Chair, Kasra Ferdows as Moderator, and Janet Godsell, Ruggero Golini, Richard Keegan, Steffen Kinkel, Jag Srai and Margaret Taylor as Panellists.

The paper is organized as follows. Section 2 presents an overview of the evolution of global manufacturing networks and changes in their spatial configuration while the following sections each focus on specific trends: re-shoring in section 3, and the enabling technological developments of next generation manufacturing in the form of additive manufacturing and lean programs in section 4. Each section starts by describing briefly the specific trend and its evolution in recent years and offers insights into its likely impact on global manufacturing networks in the future. Finally, in Section 5, we discuss the combined effect of these broad trends on the evolution of manufacturing in the world.

2. Design of Global Manufacturing Networks

Since the early 90's globalisation has meant that the design of global manufacturing networks has become a critical task for multinationals, as they sought to integrate the benefits of location, be it access to low-cost labour, specialist resources and/or emerging markets, into their operations. Initial research on internationalisation, considered how business units might 'replicate' overseas or whether more centralised models would provide scale advantages. Skinner (1969) introduced within the factory operations context the possibilities of network heterogeneity (e.g. centralised scale plants or dispersed low volume manufacturing, internal make vs outsourced buy strategy) in his seminal paper on distinct plant roles in international manufacturing. Gereffi et al (2005) explored the governance and partnering arrangements within global value chains, a dynamic process as product structures continue to evolve, with some industries moving to networked models with intermediate goods contributing significant elements of the final product. Dunning and Lundan (2008) considered firms' choices regarding geographic location and ownership, taking a process view of the value chain activities undertaken in terms of the economic and knowledge flows within and between firms.

Much of the academic discourse within Operations Management had been dominated by continuous improvement practices. Drawing on the strategic management literature (Miller 1986, 1996, Mintzberg et al 1998), the 'configuration' of networks introduced the network concept of how structure might influence capability into the field. Configuration concepts initially considered single firm 'production networks', but were applied progressively to the extended, and more dynamic inter-firm supply network context (Srai and Gregory 2008). Here, multiple case-based research studies suggested that intrinsic capabilities of particular network forms contribute to enhanced performance, in addition to the traditional recognition of efficient operational processes and organisational routines. Examples included highly centralized global operations for high value density products (e.g. fabrication labs), with cost and scale advantages, modular production integrated with digitally programmable components (medical devices) supporting mass customization at speed, and geographically co-located operations (telecoms equipment) that enabled late product flexibility and risk hedging capabilities (Srai and Gregory 2008). The design of manufacturing networks thus moved from single plant-level process improvement and value stream optimisation projects, and single firm production network footprint design, to inter-firm supply network configuration studies that integrated sector and geographic contexts into the design of global operations. Location decisions, in highly partnered service network environments for example, require consideration of an inter-firm product-service context (Harrington and Srai 2012), where co-located activities operate within agreed protocols or 'concept of operations' as seen in airports, military bases, and hospitals.

Current Perspectives

Although network design has been extended to supply networks, in practice this was limited predominantly to first tier supplier and customers. Only recently have firms begun to migrate from 'on-time-in-full' measures to the first tier customer warehouses, to more downstream metrics as on-shelf availability (retail), military effects (defence) or consumer outcomes (Srai and Christodoulou, 2014). At the broader business unit level, globalisation and advances in communication and IT has meant that many firms have also undergone functional slicing (Rugman et al 2011), and do not operate any longer as geographically bounded business units with co-location of functions. Rather they operate with functional activities dispersed internationally and managed regionally or globally to control costs and exploit capabilities (Mudambi, 2008). Within manufacturing operations, vertical disaggregation driven by waves of outsourcing has meant that the task of manufacturing network design has become predominantly an inter-firm activity, involving supply network design considerations, and also requiring inter-functional understanding to ensure activities that need to be closely coupled are co-located, and those that need not can more easily exploit locational advantages.

This understanding includes consideration of the activities across the ‘value chain’, and the broader value network of external partners.

From an operations management perspective, therefore, the network design task, has become a more strategic activity for firms, as the link between structure and capability becomes intertwined in highly networked productions systems with multiple choices on ownership, location, and integration. This task requires understanding of the coupling requirements between value chain activities, of the transferability of knowledge, processes and materials, of the activities firms regard as core and of how firms might best integrate external capabilities in a more networked and distributed model. New corporate roles responsible for network design are emerging that can address the value chain complexities of location decisions, the interdependencies between value chain activities, assessing both tactical opportunities and longer term considerations as firms reconfigure their operations on a semi-continual basis. Key considerations beyond the usual cost and quality measures include security of supply, network resilience, and sustainability. Location decisions remain vital in this design task which may involve political, regulatory and social considerations. Accordingly, the integration of production process design in support of improved supply network dynamics is now part of the operations management research agenda. The consideration of network risks has also entered the design criteria, as some sectors for example require product traceability and assurance, or awareness of resource scarcity, irrespective of the disaggregated character of the manufacturing systems. Finally, social and environmental sustainability has also become a network design criterion creating a new dimension in the evaluation of: country-level factors such as local laws and regulations, infrastructure, institutions; and node-level factors such as the role and responsibilities assigned to a plant or a supplier (e.g., Brown et al., 1993).

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The need and opportunity to span a network of industrial players that captures the operational footprint and a disaggregated value chain (Srai and Alinaghian, 2013) that previously a single vertically integrated firm would have represented, has fundamentally redefined the 21st century network design task. The manufacturing network design tools of the future will be required to enable improved integration across value chain activities. The dynamics of internationalisation itself have also changed with the recognition that, in the case of developed countries, both off-shoring and re-shoring trends are now simultaneously at play as explored in section 3. Another key phenomenon that has redefined network design has been the extending of boundaries beyond the traditional firm and its immediate first tier suppliers and customers. Consumer demands for more ethical supply chains have intensified the pressure to encompass consideration of the entire network to ensure integrity of both the product and supply practices. Product integrity failures have been particularly consumer sensitive in the food sector (e.g. the European horsemeat scandal), whilst poor working conditions and infrastructure in some contract manufacturing organisations (e.g. the recent collapse of the apparel factory in Bangladesh) has led to re-examination of sourcing strategies. Increasingly, manufacturing operations will be judged on 'outcomes' that go beyond the immediate customer and consider the 'end-to-end' extended supply network. Examples of end-to-end supply initiatives include: UK healthcare where 'patient outcomes' and compliance with prescribed treatments (medical devices) will replace on-time-in-full delivery of the physical drug-product to the distributor; defence aerospace where the provision of fully functional aircraft 'flying hours' will determine quality supply (BAE Systems); the entertainment sector where the 'play' experience constitutes successful product delivery (Lego); and mass market fast moving consumer goods where companies manage their respective retail aisles to optimise in-store availability (Unilever). This extension to 'end-to-end' requires a reassessment of performance metrics that reflect the extended boundary conditions and more effective integrative processes and information systems across network partners (Harington et al, 2013). As network complexity increases, designers will need to consider self-adapting manufacturing systems that operate without multiple human interventions, supporting a variety of co-existing supply chain replenishment models.

Recent research has also considered how network designers might redefine the product, or even the production technology, previously regarded as largely fixed system constraints. This network design approach considers how alternative production processes might facilitate/constrain 'end-to-end' supply network dynamics. Design criteria, primarily driven from an end-to-end systems perspective thus include technology selection, or even proactively drive new production technology development, rather than assuming these to be fixed parameters. This approach challenges the traditional, predominantly sequential, process of new product development where laboratory methods, often with limited regard for the supply dynamics they might require, drive initial production model selection. This network design approach may generate production facilities that provide radically different scale, flexibility, and variety options to better serve the market or end users. Examples include the emergence of new technologies, such as continuous crystallisation in batch-centric pharma (Srai et al, 2014), or additive manufacturing in aerospace, where these new processes fundamentally redefine the network footprint. (We explore the effect of additive manufacturing in more detail in Section 4 of the paper.) Invariably radical change, particularly in highly regulated industries, requires consideration of the wider industrial ecosystem, where institutional players and regulators need to embrace these alternative production and delivery processes.

Network design considerations from an operations risk and resilience perspective are now informing location decisions (Kumar and Gregory 2013) by evaluating interactions between firms and suppliers, and their exposure to extreme events. Key concepts that are now in the literature on network resilience include how the structure of networks (nodes, location, co-location, and node-length etc.) influence operational risks including those that have a geographical context, be it socio-political or extreme natural phenomena. This consideration entails examining climate and earthquake data, where risk analyses exploit advanced network modelling and draw on multiple datasets.

Sustainable supply network design (Srai et al 2013) requires consideration of network structure, and the capabilities of firms to perform operational processes across the distributed network. In the design of sustainable global manufacturing networks, a key role is also played by the level of competences of the different nodes in the network that can range from production competences to procurement and supply chain, and to product/process innovation (Ferdows, 1997b; Vereecke and Van Dierdonck, 2002). Sustainability initiatives are typically cross-functional and they might include product and process designs, manufacturing, distribution, procurement and supply management simultaneously (e.g., Zhu and Sarkis, 2006). As a consequence, a broader competence of one node was found to be related to a higher sustainability programs and performance (equally social and environmental) (Golini et al.). As a matter of fact, when their competences are higher, the nodes can enhance sustainability of the whole network by leveraging their geographical proximity and social connections to foster effective collaboration with local institutions, NGOs and suppliers (Ageron et al., 2012; Chen et al., 2009; Gualandris et al., 2014).

Furthermore, as real-time information systems develop, the emergence of new last mile solutions will aim to support industry responses to meet same day consumer purchase habits that will be electronically captured. The now ubiquitous ‘app’ is allowing consumers to interact with their last mile suppliers and expecting ever-shrinking response times. Future network design will aim to respond to these near real-time demand signals, and inevitably drive postponement and last mile distribution strategies that support more customised solutions.

Finally, with so many fast-changing factors impacting the global manufacturing and supply chains, many authors have emphasized the need for designing them with high levels of flexibility (Brace, 1989, Bowerscox and Daugherty, 1992; Kendrick, 1998; Vollman et al., 2000, Fröhlich and Westbrook, 2002; Heikkla, 2002, Godsell et al., 2006). Some authors have differentiated between "dynamic flexibility" and "structural flexibility" of supply networks. "Dynamic flexibility" is commonly achieved by increasing the "agility" of the company's existing factories, suppliers and its extended supply chains (Goldman et al., 1995; Naylor et al., 1999; Christopher and Towill, 2000; Mason-Jones et al., 2000; van Hoek et al., 2001). "Structural flexibility" refers to the ease of *re-configuring* the company's global supply network in response to changes in demand, technology, local conditions, disruptions, and other factors in its operating environment (Christopher and Hölweg, 2011).

Structural flexibility ultimately challenges the current norms regarding the way supply chains are configured and managed. It suggests that companies should go beyond making their current factories and suppliers more responsive, but develop the capability of changing the structure of their network quickly when needed—that is, make it easier to *reconfigure* their existing supply network. They need to put the infrastructure in place which can re-route the flow in their supply networks, for example, allowing going to an alternate supplier for an urgent order (if their current supplier happened to be short of capacity at the time), or set up a new system to fulfill sudden changes in on-line orders from international markets.

Managers need new tools for analyzing how much structural flexibility they should build in their networks. Models based on "real options" can help (Christopher and Hölweg, 2011). For example, a leading European low cost apparel manufacturer uses a real option model to determine the list of suppliers it pre-approves and reconfigures its supply network for each season by receiving bids from them (Mataraarachchi et al., 2014).

3. Re-shoring

The redesign of manufacturing networks is linked closely to the strategies of firms to move production activities offshore and, also, back to their domestic base. Increasingly, policy makers and academics are investigating the so-called re-shoring (or back-shoring) of once off-shored manufacturing capacities back to the home country (Kinkel, 2014; Kinkel, 2012; Kinkel and Maloca, 2009). The current debate on re-industrialisation (Pisano and Shih, 2009, 2012a, 2012b; Foresight, 2013) in the US and Europe is to some extent based on expectations that back-shoring activities of manufacturing companies might help to restore industrial competitiveness in high-wage countries. This debate is fuelled by the assumption that cost advantages of important low-wage countries, in particular China, may be gradually eroded by higher wage increases in the next five to ten years (BCG, 2011; Kinkel , 2014). But so far, empirical evidence on back-shoring and foreign divestment is only slowly starting to emerge and more knowledge about its drivers, effects, and its likely evolution is needed.

The German case

The case of German manufacturers is illustrative. Drawing on German data from the *European Manufacturing Survey (EMS)*, we compare companies' back-shoring/re-shoring activities from 2010 to mid-2012 with previous periods. EMS is a survey on the diffusion of advanced production technologies and organisational concepts in European manufacturing industry. The German data set is one of the few available that allows longer-term trend analysis of re-shoring activities ranging back to the mid 1990s. The current German dataset includes 1,594 responses of German manufacturing companies in the 2012 survey round and between 1150 and 1650 responses in each of the previous surveys in 1997, 1999, 2001, 2003, 2006, and 2009. The distribution of the sample is representative of the basic population of all German manufacturing companies. German evidence on re-shoring might be indicative of trends in other developed and high-wage countries with strong capabilities in medium-high-tech-manufacturing and opportunities for global innovation for local markets, e.g. in automotive, machinery and equipment, electrical machinery, chemical industries (McKinsey Global Institute, 2012).

Frequency of back-shoring/re-shoring activities.

Back-shoring/re-shoring of production capacities has been undertaken by only 2 percent of German manufacturing companies from 2010 to mid-2012. It has *decreased* continuously since around 2001, when German companies were very active in off-shoring and re-shoring. Since 2008, they seem to be more risk-averse and strategically selective with cost-oriented relocations to low-wage countries, which can reduce the level of back-shoring in subsequent years. When extrapolated, absolute numbers account for around 400 to 700 companies performing back-shoring activities per year (Kinkel, 2014). In parallel, production relocations of German manufacturing companies abroad continued to decline from an already low level to its lowest level (8 percent of the German manufacturing companies) since the first measurement in the mid-nineties. Hence, for every four off-shoring company there is currently one back-shoring company. Figure 1 shows the trend in off-shoring and re-shoring activities over time.

Insert Figure 1 approximately here

On the whole, the evidence from this survey suggests that back-shoring of manufacturing activities from low-wage countries, while relevant and measurable, is not a strong trend. Over the past 15 years, the ratio of back-shoring to offshoring (relocating) companies has been relatively stable at one to four (Kinkel, 2014). Further evidence of back-shoring activities in other developed European countries which the EMS is covering (e.g. Austria, Denmark, Finland, the Netherlands, Switzerland, Slovenia, Spain) shows a similar pattern for the period of 2007 to mid-2009 (Dachs and Kinkel, 2013), indicating that a ratio of one re-shoring company to three to four off-shoring companies may also be common in other developed countries with strong manufacturing capabilities. However, the November 2013 Manufacturing Advisory Service National Barometer on English manufacturing SMEs found that in the preceding 12 months, 15 percent of companies were bringing or had brought back production in contrast to only 4 percent that had off-shored production. In addition, 18 percent of respondents indicated that they were planning or considering on-shoring. Also the 2013 survey of US-based manufacturers found that 21% planned to re-shore some of their production (BCG, 2013). Thus it seems that patterns of re-shoring and off-shoring can vary by geography.

Reasons for Re-shoring

The ability and flexibility to deliver on time and control of quality rank first and second as reasons for back-shoring (see Table 1). The flexibility of trans-border supply chains to react to last-minute changes of customer requirements and the ability to supply international customers in time seems to be a strong motivation for re-shoring initiatives, particularly performance targets cannot be fulfilled because of complex and time-consuming, trans-border supply chains. Another motivation is quality assurance and, more broadly, management processes which are also often not easy to transfer to a foreign operation (Kinkel and Maloca, 2009; Schulte, 2002). It is especially challenging when the parent company is a quality leader (as many German companies are) and has deep knowledge embedded in its management methods at the parent site.

Insert Table 1 approximately here

An instructive example is the German high-quality toy manufacturer STEIFF. The company had offshored large parts of its manufacturing activities to China in the late 1990s. Despite intensive efforts to transfer quality management systems to China, assuring product quality was always a challenge: cross-eyed teddy bears do not look very endearing to small children especially for a company that is known for its high quality and expensive teddy bears!. Another issue was the flexibility to fulfill short-term orders. When at the end of 2006 a tiny ice bear baby named Knut was born in Berlin Zoo, suddenly many kids in Germany and Europe wanted a plush ice bear, leading to 80.000 orders in only a few months. Since it took 8 weeks to receive shipments from China, the company was not able to fulfill all customer orders and missed significant sales. These issues were instrumental in the decision to bring back the outsourced production from China in gradual steps from 2008 until 2010 to its domestic location in Giengen, Germany.

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Overall, while companies continue to internationalize their activities, there seems to be a gradual shift in the reasons for doing that. The advantages of cost-based relocation activities to low-wage countries seem to be diminishing and market-related expansion investments in emerging markets seem to be gaining greater significance. Companies with their home base in high-wage countries such as Germany are also increasingly focusing on utilizing the strengths and potentials of their factories in their home base. We might see the beginning of a stronger imperative for *local manufacturing* in strategic markets, characterized by either high volumes, dynamic growth potentials or lead customers in specific technological areas, with a strong focus on regional concentration and specialization of the necessary engineering and manufacturing competences. This will call for building the capability to provide “complete solutions” in these strategic markets, reversing the trend to fragment global supply chains

(McKinsey Global Institute, 2012). This reversal questions the benefit of spreading the production of individual components to low cost locations against the cost of the steering and controlling complex, multi-stage supply chains, which can easily include 30 or more different players and locations. Such fragmented global chains are vulnerable to damage to any one of their links. The Fukushima disaster disrupted supply chains due to inputs from Japanese suppliers becoming unavailable and is an example of such damage.

Other factors supporting local manufacturing, with a focus on more onshore, localized and integrated supply chain activities (Foresight, 2013) are:

- Providing customized products and services, making it necessary to develop and produce customized solutions in smart and agile (responsive) modes close to local clients (Forfas, 2013; Foresight, 2013, McKinsey Global Institute, 2012).
- Rising labor costs in emerging countries as a result of their economic catching-up processes, rendering their comparative cost advantages more and more marginal compared to developed countries with a highly skilled workforce and lower wage volatility (Forfas, 2013, Foresight, 2013).
- Reduced weight of labor costs in total production costs, due to continuing automation and efficiency improvements in many manufacturing firms. For example, in German manufacturing industry today direct labor cost account for only around 10 percent or less of production output value.
- Rapid pace of innovations in information and communication technologies and manufacturing technologies towards smart and digital factories (Forfas, 2013; Foresight, 2013; Germany Trade & Invest, 2013) allowing new methods of production which are changing the traditional production systems. An example is the "additive manufacturing," with a disruptive potential to deliver "individualization for free". (Germany Trade & Invest, 2013, McKinsey Global Institute, 2012). We discuss additive manufacturing in the next section of the paper.

Reflecting on the somewhat mixed evidence to date, it is unclear as to whether re-shoring of manufacturing activities will be a major thrust in restoring industrial competitiveness in high-wage countries that have lost manufacturing capabilities. The pressure for greater flexibility and responsiveness is likely to grow into the future thus suggesting increasing consideration of re-shoring and near-shoring options. The decreasing cost of energy in the USA is impacting the location calculus for firms making it a more attractive location. However, it is not easy to restore product and process competences outsourced some years ago and restore their "industrial commons" (Pisano and Shih, 2009). In many cases it might be easier to build up capabilities for the next generation of products or technology, as re-learning of once outsourced competences can be a difficult process and provides only catching-up instead of leading positions. Nevertheless, back-shoring is a reasonable strategy for some companies, particularly those that are striving to adapt to rapidly changing global markets and improve responsiveness and proximity to local customer needs while supporting local manufacturing.

4. New Production Systems

Global manufacturing has historically been profoundly affected by changes in production methods. Some of these changes, like computer aided manufacturing, have triggered rapid alterations in the pattern of production around the globe, while the effect of others, like introduction of just-in-time or total quality management, have been more gradual. Production methods naturally continue to change, and in this section we focus on two current trends that deserve special attention: first, the radical, and potentially disruptive, change in production method commonly referred to as "additive manufacturing," and second, lean manufacturing, which has been reshaping the competitive landscape of manufacturing gradually but profoundly.

Additive Manufacturing

Additive manufacturing (AM), also known as "3-D Printing," builds artefacts through progressive layering of material following instructions directly from a design software. This technology represents a game-changing alternative to the conventional "subtractive manufacturing" in which excess material is removed to make the finished item. In offers ground-breaking opportunities to manufacture items with improved functional and aesthetic properties over those produced using the traditional method. It can not only make objects which would be practically impossible by traditional methods, but also completely new products. For example, 3-D printing can be used to produce a replacement of human ear using living cells (Cornell Chronicle, 2013). This is truly a disruptive technology, which has been hailed by some scholars as the Third Industrial Revolution (The Economist, 2012) with the potential to transform our lives (Lipson, 2012).

Our focus here is on the managerial implications of additive manufacturing. We draw primarily on the findings of a recent survey of AM users internationally, which investigated the knowledge and views of these users about the applications, benefits, and developments of the AM technology (Taylor et al., 2013). The results provide insights into the impact of AM on re-shoring, business models, and sustainability.

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- *Impact of AM on Re-shoring*

As we mentioned in Section 3, AM has the potential to accelerate the pace of re-shoring. This is confirmed by Taylor et el. (2013). The AM users anticipate that the motivation for re-shoring would be particularly strong for items that are high value, customized, complex in design, high quality, advanced technology, specialized and produced in low volumes. For example, many items in the aerospace and performance cars would be good candidates. AM is unlikely to become competitive for high volume production against factories in low labour cost countries. An alternative perspective emerging from some users suggests is that AM is not likely to herald a significant change in the locus of manufacturing because it is slow, expensive, and can equally be adopted by those low-wage countries where global manufacturing currently dominates. If the former, more widely-held viewpoint is valid, arguably for organisations to overcome the barriers to re-shoring they should adopt innovative business models which harness the technical capabilities and distinguishing characteristics of AM.

- *Impact of AM on New Business Models.*

A further consequence of the universality of AM equipment is the ability to co-locate design with manufacturing. As described in section 2, the benefits of this, which include greater flexibility and risk-hedging capability, are increasingly recognised. Taken together with other features of AM, users see this as offering potential for business performance improvements such as increased speed and quality of design (e.g. by the ability to make more frequent prototypes), cheaper production costs, reduced processing requirements and the provision of a full service (Taylor et al., 2013). In this regard, AM use contributes to the 'servitization' of manufacturing - described in Section 1 - as a growing trend within the global manufacturing landscape. Customer service improvements include faster turnaround, reduced costs, higher quality, improved aesthetics, customized products, greater responsiveness and flexibility. It is all these benefits that point the way towards determining the innovations and business changes that are required to exploit AM successfully.

By way of illustration, users who took part in the survey reported adopting new business models, moving into new markets and developing new product lines as a result of using AM (Taylor et al., 2013). Several described how - as a result of being able to offer a complete manufacturing service rather than just design and prototyping - the adoption of AM created opportunities that required new approaches to conducting business. Others reported altering the way they operated their business to facilitate online ordering and the exchange of digital data for producing customized parts more easily. Yet other users pointed to changes in the ways they marketed and sold their products, particularly making increasing use of digital media to access global markets.

Finally, the legal implications of conducting business remotely following the exchange of digital data, have led to re-designed customer contracts which afford greater protection to the manufacturer. This development reflects just one example of how AM can alter the way companies engage with their customers.

- *Impact of AM on Customer Engagement.*

Companies that offer AM services are likely to be working closely with their customers. They can offer improvements in design, prototyping and manufacture through an iterative process with their customers much easier than the conventional production systems. They can work closely with their customers as they design brand new products and let them exploit the superior capabilities that AM offers. However, this process can also lead to raised expectations on the part of customers, making the upgraded performance the expected norm—sometimes even exceeding the current AM capabilities (Taylor et al. 2013). This suggests that customers need to be ‘educated’ about the limits of the AM technology—e.g., mechanical and surface finish properties, cost curves and capabilities of post-processing operations.

- *AM’s Impact on Conservation of Natural Resources.*

As discussed in Section 2, conservation and use of sustainable production systems are among the growing concerns for many manufacturers globally. Additive production, by its very nature, conserves materials, in the sense that instead of *extracting* the object by removing (and usually wasting) the unneeded parts from a block of material, it builds it from scratch and uses only as much material as the object needs. Aside from material savings, since manufacturing can be undertaken closer to the point of demand, transportation and logistics costs can diminish. Similarly, manufacturing just-in-time and on demand rather than for stock will reduce overproduction and the need for warehousing and storage will lessen. For example, a survey respondent reported establishing a global network of over one hundred 3-D printing sites to serve local markets (Taylor et al., 2013). The results have been lower transportation costs, and reduced need for storage warehouses and distribution centers.

A further set of environmental benefits derives from features of 3-D printed parts themselves. The ability to manufacture complex designs additively means that products can be of lighter weight. This ability not only reduces the use of materials, but can have substantial indirect benefits. For example, lighter parts in the aerospace and automotive sectors can reduce energy consumption during the life of the final product, and less material to dispose at the end of its life. Some users also argue that the ability to build truly customized items, resulting in more satisfied customers, is likely to reduce the urge for replacing the items, leading to still further reduction in product disposal.

Despite these clear advantages, there are studies that suggest that the empirical evidence so far indicates a more complex picture about the potential for the 3-D Printing to deliver environmental benefits (e.g. Sissons and Thompson, 2012). For example, some argue that instead of reducing the consumption, AM, with its ease of making a replacement, can lead to *increased* consumerism and extend a throw-away society. Others have voiced concern over environmental problems associated with the disposal of AM process waste and potential inefficiencies with the decentralized manufacture that results from a proliferation of production points. While there are strong reasons to expect that the impact of AM on the environment is positive, there are still gaps in the current knowledge that need to be addressed by future research.

Lean Programs

The focus in lean is on the “soft” side of operations, changing production routines and engaging the hearts and minds of people to improve processes continuously. A lean program starts with the analysis of value for customers—their needs, wants and desires, vocalised and non-vocalised. It then aligns the resources from sales and marketing, design, procurement, manufacturing, logistics and warehousing, human resources, administration and customer support to understand where this value is created, retained and lost by operations within a firm and up and down the value chain. Armed with this insight, successful companies can modify their global supply chains gradually and continuously to deliver maximum value for their customers with minimum waste.

Where Next?

Nowadays it is difficult to find any global manufacturer that is not pursuing lean principles. Many leading companies, such as Bosch, Siemens, Lego, Kerry, Daimler, and Volvo have introduced their own formal lean "Production Systems," all of which are based on the renowned Toyota Production System (Netland and Ferdows, 2014). These production systems are designed to inculcate a culture of practicing lean principles in every factory and eventually in the rest of supply chain and other functions in the firm.

The experience at Bosch illustrates this point. Spanning the globe with sales of over €46 Billion, employees of over 280,000 with 174,000 located outside Germany, the company uses the Bosch Production System (BPS) as a means to improve its production across the globe. BPS is based on the lean principles and it has evolved since it was introduced in 2004. A recent visit to their Bosch Thermo plant in Stuttgart showed that the BPS has now evolved from a purely tools based system to one where the focus is now on the "Way", how to engage the hearts and minds of staff when they are using the tools and techniques. This has very strong resonances with the Toyota Way and the Toyota Production System (Liker, 2004).

Successful implementation of a lean program has enabled some factories in advanced countries (operating in a high-cost environment) to remain open or even re-shore or insource production from offshore locations, Bosch continues to employ 107,000 people in Germany and thousands more across Europe. Similarly, an offshore factory in a low-cost environment that has implemented the lean principles skilfully, and thereby enhanced and augmented its advantage, can become a formidable competitor and motivate transfer of more products to it.

However, implementing a lean program globally is not an easy task. It requires long term commitment, allocation of substantial resources and expertise in balancing between the tools for improvement and the engagement of people to improve processes. Bosch has an in-house consulting group to help associates understand and adopt BPS. The development of the production system within Bosch is supported at the highest level, with a board member having full responsibility for its development.

Lean programs can improve operations in any location around the globe. Factories in advanced countries can make themselves more competitive by implementing a lean program more widely and extensively to compensate partly for their high cost environments. On the other hand, factories in the low cost environments can do the same, which makes them even a more powerful competitor. There are clearly cases where more extensive use of lean can ensure the long term viability of a factory in the company's global network. Therefore, although lean is "soft" and its effect is gradual, it continues to be a powerful force in manufacturing in future.

5. Conclusion

A central question in this paper is whether the combined effects of the emerging trends described above are creating a pivotal (or radical) change in global manufacturing configuration or simply creating incremental adjustments at the fringes. We conclude that the latter is more likely to be the case.

The trends discussed in this paper are important and deserve attention. Some of them suggest that a fundamental shift in the characteristics of global manufacturing is possible in the future. However, in the more foreseeable future, they are not likely to make a major dent in the way in which most companies configure their production networks globally. Disruptive technologies, like additive manufacturing (AM), are still in their infancy, and we should be careful not to extrapolate too far. It is useful to draw a parallel with the history of robotics in manufacturing. Three decades ago, when industrial robots were still in their infancy, many believed that wholesale automation of factories ("lights out") was around the corner. It turned out to be hype and neither the pace nor the magnitude of spread of robots matched the forecast. Therefore, while the long term effect of disruptive technologies like additive manufacturing is potentially significant, it is still too early to assess their likely impact.

Similarly, re-shoring is not happening on a large scale, and, as we explained earlier, it is advisable only under certain conditions and, even then, it may not be easy to implement. Sustainability, while it is emerging as an increasingly important factor, is still not widely prioritized by many companies. Multinational corporations have been responding to the sustainability call through a series of initiatives, such as ethical sourcing, green and energy efficient processes, environmentally friendly products and participation in social and humanitarian projects often in collaboration with NGOs (e.g., Haugh and Talwar, 2010). But they have also been facing challenges. For instance, they are expected (by customers first) that each step in the supply chain in their global network follows the same standards in terms of social, ethical, and environmental sustainability (e.g., codes of conduct, environmental behaviour) (Chen et al., 2009; Park and Vanhonacker, 2007). Finally, "Big Data" and the "Internet of Things" can have profound effects on configuration of global manufacturing, but, so far, they seem far from making a disruptive impact on it.

Therefore, while many arguments are being advanced that the global configuration of manufacturing may be at a tipping point, it is instructive to view the drivers from a global, and macro, perspective. Off-shoring and outsourcing, arguably the strongest drivers that shape the configuration of global manufacturing, are continuing almost unabated. Trade in goods and services has expanded at more than twice the rate of the growth of global economy in the last three decades, and there is little evidence that this trend will subside in the foreseeable future. This implies that the global proliferation of manufacturing and the fragmentation of global supply chains are likely to continue. Of course it will vary by industry. For example, the recent experience of Boeing in the production of its Dreamliner shows that for highly complex products like a new aircraft, there are limits to how far its manufacturing should be outsourced and dispersed around the globe. But these limits are imposed primarily by the inherent difficulty of coordinating the interactions and outputs of multiple sites dispersed around the world than any new trend, including the ones described in this paper.

Nevertheless, while the individual and collective impact of these trends is still only at the fringes of global manufacturing and not at its core, we can garner a few critical insights for the future. The trends suggest that improving the structural flexibility across the entire network is becoming more important strategically, particularly in terms of being able to adjust to unanticipated shocks. Similarly, leveraging the capabilities of information technology and harnessing the potential of Big Data across the whole network on an "end to end" basis are also among the key capabilities for manufacturers in future. These capabilities can enable the manufacturers to provide more services to their customers and end users of their products. It can allow them to devise innovative business models that can serve as the basis for new revenue streams. Thus the so called “servitization of manufacturing” will deserve increasing attention.

Servitization requires knowledge of the value stream for customers, which is also demanded by another mandate facing manufacturers: developing an “end-to-end” perspective of their global production and supply networks. Since a supply chain is as strong as its weakest link, manufacturers must pay attention to every step in their global network of suppliers. This means building increasingly closer collaborations with all actors in their extended global supply chains—from downstream operations and end users to extended upstream suppliers. Many of these actors are outside the traditional networks of typical manufacturers—for example, they may be end users of their products produced by their immediate customers, suppliers of their suppliers, or third-party reverse logistics providers—hence, manufacturers must build new linkages.

The end-to-end perspective is particularly important for meeting the demands for increased sustainability. A company’s entire global supply chain must follow environmentally friendly strategies that address, for example, waste reduction and reuse, energy and water consumption, pollutants, and other factors that can impact the environment. In practice, that would require empowering each of their own globally dispersed sites to build requisite competences for improving sustainability of their own operations, and extend it to their direct suppliers, and eventually suppliers’ suppliers and their *extended* global supply chain. Manufacturers of the future must expand their reach in many directions beyond their factory walls.

The mandate of getting closer to actors in the extended supply chain is not only for those in upstream operations but also those downstream: customers of the customers. Another recurring theme in this paper is the importance of customer engagement. There is a consensus that a promising strategy for manufacturers in the future is to intensify their forward facing activities focused on customers. For example, to exploit the opportunities offered by additive manufacturing, the manufacturer must be closely engaged with its customers.

Does re-shoring reduce the urgency of these mandates? We do not think so. First, the scale and scope of re-shored operations, compared to offshored, is still very small. While there appears to be a widely held view that re-shoring will show significant growth into the future, the data so far does not support that view. Second, re-shoring is potentially beneficial only under certain conditions: when the costs in offshored sites have increased substantially, when there is high value in bringing design and production closer to each other (typically when the product is complex or time sensitive), or bringing production closer to market (for more customization, better quality control, protection of intellectual property, etc.). Besides, re-shoring often requires existence of a vibrant "industrial commons" (Pisano and Shih, 2009) which may have eroded in many advanced economies. Therefore, while in certain sectors and industries (like the mid-size German machinery manufacturers) we might observe some re-shoring, a large scale movement in that direction is probably unlikely. The challenge of restoring the industrial commons should not be underestimated. For example, even for a relatively simple industry like apparel where the production cost relative to off-shored production have narrowed, American companies are finding it difficult to move production to the US being constrained by the scarcity of qualified workers (Clifford, 2013). We do not expect to see the pace of re-shoring becoming greater than the pace of offshoring any time soon.

However, new technologies, the "end-to-end" approach, servitization of manufacturing, new business models based on agility and customization, and concerns for sustainable and ethical extended supply chains are creating exciting opportunities for manufacturers, particularly in the developed economies. Next generation manufacturing will depend increasingly more on an in-depth understanding of markets and customer needs, operations that are probably highly capital intensive, knowledge intensive and skills intensive, a participative company culture which involves proactive and open communications between management and staff who embrace continuous change**.**

These trends are also providing even more exciting opportunities for research, especially for scholars in the field of operations management. Among the over-arching challenges are development and validation of the innovative business models that are likely to be required if the insights for the future enumerated in this paper are to materialize in practice.

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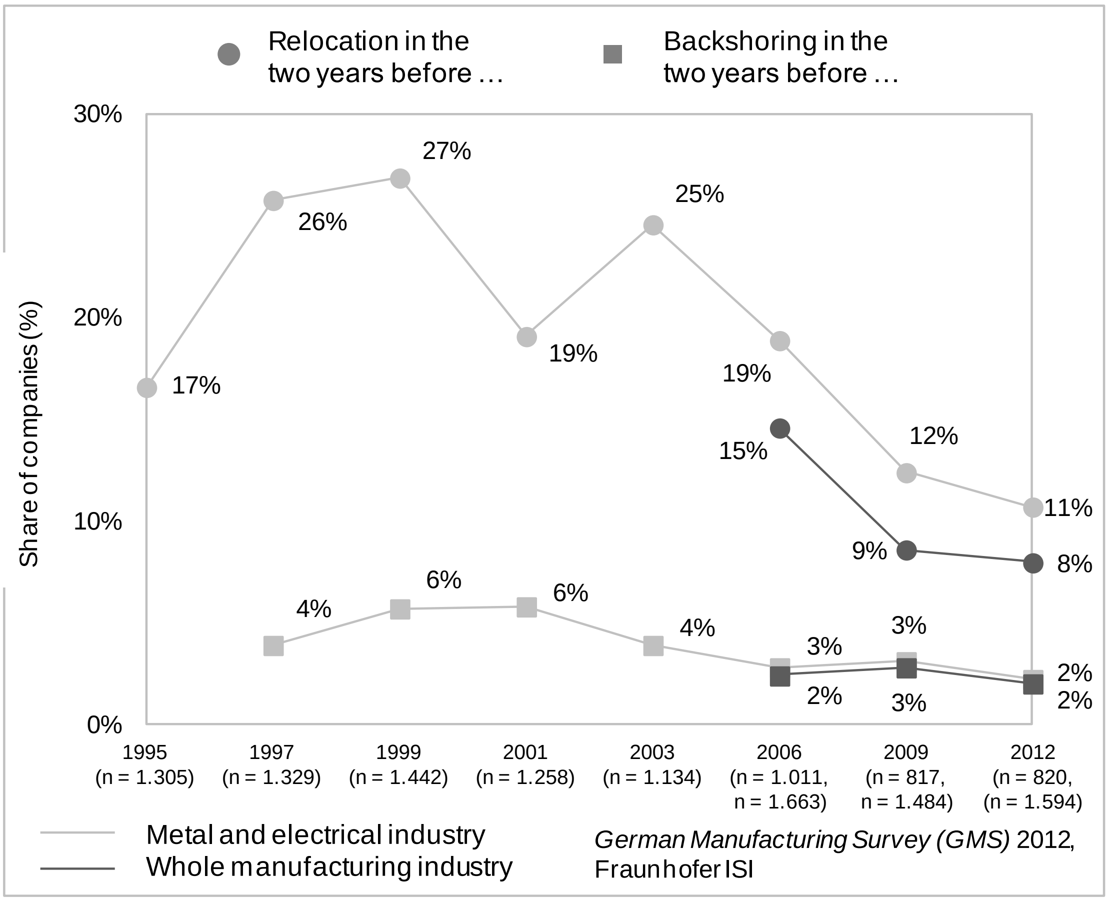

Figure 1: Relocation and back-shoring activities over time.

Table 1: Motives for Production Back-shoring from Abroad to Germany

Main motives for production backshoring	Production backshoring mid 2004 to mid 2006	Production backshoring 2007 to mid 2009	Production backshoring 2010 to mid 2012	Trend
Flexibility/ Ability to deliver on time	72 %	43 %	59 %	↘↗
Quality	61 %	68 %	53 %	→
Capacity utilization	n.a.	n.a.	28 %	n.a.
Transport costs	n.a.	32 %	25 %	(↘)
Coordination and monitoring costs	16%	20 %	21 %	→
Infrastructure	15 %	n.a.	13 %	→
Availability/ Fluctuation of qualified personnel	9%	19%	13 %	↗↘
Loss of Know-how	n.a.	5 %	13 %	↗
Labour costs	16 %	33 %	6 %	↗↘
Vicinity to R&D at home	n.a.	2 %	4 %	→