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Delayering the global production network into congruent subnetworks

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A B S T R A C T

The literature in operations management has not kept up with the growing complexity of and opportunities offered by global production networks. Managers need new tools to cope with this complexity. We propose one that is based on a model that delayers the global plant network into a set of subnetworks on the basis of complexity and proprietary information in the products they produce and production processes they use to produce them. This allows examining whether each subnetwork is *congruent*—i.e., has an appropriate manufacturing mission and the competencies that it would need to carry it out. We apply this tool to analyze the global production networks of five companies and illustrate its usefulness in performing periodic audit of the global production network and identifying potential strategic anomalies that deserve attention.

1. Introduction

The literature in operations management, on the whole, has not kept up with the increasing complexity of global production networks. After years of intense offshoring, outsourcing, global procurement, and expansion into new international markets, the global production network of a typical multinational manufacturing company today consists of plants dispersed around the globe, each under increasing pressure to coordinate its operations with each other and with the rest of its supply chain, which itself is becoming increasingly more global and fragmented. Meanwhile, the multitude of factors outside the control of the company or the plant, ranging from changes in foreign exchange rates and new trade agreements to emergence of new competitors and new technologies, continue to require adjusting the structure of these networks constantly. In addition, changes due to the firm's own decisions—such as introduction of new products, entry into new markets, mergers and acquisitions, or a shift in strategy—can rapidly turn a well-configured network into a poor one.

An important implication of this increasing complexity is the need for expanding the focus of research in this field from examining the role of individual plants in the network (Hayes and Schmenner, 1978; Collins et al., 1989; Ferdows, 1989, 1997a,b; Chew et al., 1990) to assessing missions and capabilities of *networks* of plants (Shi and Gregory, 1998; Jagdev and Browne, 1998; Karlsson and Skold, 2007; Ferdows, 2008; De Meyer and Vereecke, 2009; Friedli et al., 2014; Johansen et al., 2014). However, while many scholars have recognized the growing complexity and importance of these networks, the scholarly literature still does not offer many tools for how to manage them. Filling this gap deserves attention.

Among the most useful tools, we believe, are those that reduce the complexity of the network by delayering it into simpler and more manageable subnetworks. We see a parallel between the challenges that single plants were facing forty years ago and what global networks of plants face today. In his seminal article, “The Focused Factory”, Skinner (1974) observed that many plants were trying to respond to too many manufacturing missions simultaneously, which made their design and management complicated and resulted in poor compromises in achieving most of their missions. Today many global production *networks* are in a similar situation. They must respond to a wide range of strategic mandates, which makes their design and management complicated, and this complexity is exacerbated by the fact that many external factors can impact their performance significantly or make them evolve in unintended directions.

Skinner suggested that the key to simplifying the design and management of a factory was to give it a limited and coherent manufacturing mission. Such a factory can become “focused”—i.e., it can align its structural elements (e.g., equipment, layout, capacity, and process technology) and infrastructural elements (e.g., production planning and control, quality management systems, inventories, job design, and key performance measures) to accomplish its mission effectively (Skinner, 1974). We propose the same approach can be used to simplify the complexity of a production network. In other words, the notion of focus, with a few modifications, can be applied also to a *group of factories* that work together to accomplish a manufacturing mission. If a complex production network is delayered into a set of such subnetworks, each with a coherent manufacturing mission, it will be possible to focus each subnetwork, hence simplify its design and management. Does the subnetwork, in fact, have an appropriate manufacturing mission and do the factories that comprise it have the requisite competencies to accomplish it? We use the term “congruent” to refer to a subnetwork that has both a coherent manufacturing mission and appropriate competencies to carry it out. We consciously did not use the term “focused” to reduce potential confusion.

Note that a congruent subnetwork can consist of many focused factories—i.e., one concept is not a substitute for the other. In fact, they complement each other: delayering the production network into a set of congruent subnetworks allows a higher level of analysis that helps determining the focus of the plants in each subnetwork.

In this paper we offer a model for delayering a production network into a set of subnetworks and assessing their congruency. To demonstrate its utility, we apply it to analyze production networks of five multinational manufacturing companies. We show that our model serves as a useful tool for answering broad strategic questions such as:

- Are there any anomalies in allocation of products to different subnetworks of plants?
- Do the subnetworks of plants (each producing a certain family of products) possess the appropriate level of resources and capabilities to carry out their strategic missions?
- Are the strategic missions of the different subnetworks sustainable?
- Are the plants in different subnetworks in right places?

2. Literature review

Several overlapping streams of research provide the context for studying global production networks. The first stream is the rich literature on multinational companies. In the last three decades, research on the structure and organization of multinationals has shifted from a focus on a hierarchical view of relationships between the company's headquarters and its subsidiaries towards a perspective of a web of diverse inter- and intra-firm relationships. Theories that have been used to examine these relationships include network theory (Ghoshal and Bartlett, 1990; Gulati et al., 2000; Vereecke et al., 2006), evolutionary theory (Kogut and Zander, 1993), learning organization (Nonaka and Takeuchi, 1995; Grant, 2010) and knowledge transfer (Grant, 1996; Szulanski, 1996). A common theme among these theories is that multinational organizations can benefit greatly from transferring resources and competencies developed in different locations within their company.

The second stream of research, with a slightly different perspective, is the literature on industrial networks. The focus here is on the external, mostly vertical, networks in which the firms — especially original equipment manufacturers (OEMs) — operate. Relationships with suppliers (Dyer and Nobeoka, 2000), subcontractors, and contract manufacturers (Plambeck and Taylor, 2005) have received considerable attention in recent years. At a more conceptual level, Håkansson (1990) views the industrial networks as interplay between actors, resources, and activities that reside in different firms that comprise the network (where actors have knowledge of activities and control resources, and activities change or exchange the resources). A key implication of this perspective, as Dekkers and Van Luttervelt (2007), Karlsson (2003), and Karlsson and Sköld (2007) also observe, is that manufacturing strategy is best defined in the context (i.e., industrial network) in which the firm operates. In other words, the role of plants in the firm's global production network extends beyond the firm's boundaries to its level of dependence on long-term suppliers, alliance partners, contractors, design labs, distributors, arms-length suppliers, and other key actors in their relevant industrial networks. This is what Pisano and Shih (2009) mean by “industrial commons,” and how their presence or absence can completely alter the options for locating global production sites.

Since industrial networks in rich countries have historically been more advanced, this stream of research suggests that plants in these usually high-cost environments can benefit from their proximity to advanced industrial networks. The consensus among these scholars is that firms should exploit the full benefits of this proximity and be very careful when considering moving such plants offshore to low-cost environments or outsource what they produce (Arrunada and Vázquez, 2006; Pisano and Shih, 2009; Zirpoli and Becker, 2011). Although most of these scholars have focused on industrial networks in the US, Europe, and Japan, their conclusions can be applied to any industrial network, including the more recent ones in other regions of the world, like Singapore, Taiwan, South Korea and China.

The third stream of research, complementing the first two, has focused directly on the intra-firm production networks. The central question here is how each plant can support the firm's strategy both individually and as a part of the network. Skinner (1974), as mentioned earlier, suggests that a coherent manufacturing mission would allow a plant to align its structural elements and infrastructural elements to achieve this mission effectively. Such a plant would be focused. While there may be situations where a plant may choose, or need, not be focused (Boyer et al., 1996; Vokurka and Davis, 2000; Ketokivi and Schroeder, 2004; Ketokivi and Jokinen, 2006), theoretical and empirical investigations suggest that if a plant can become focused, it would improve its performance (Hayes and Wheelwright, 1979; New and Szwejczewski, 1995; Brush and Karnani, 1996; Pesch and Schroeder, 1996; Bozarth and Edwards, 1997).

Hayes and Schmenner (1978) suggest that plants in the firm's production network can be organized along products, processes, or a combination of the two, and discuss under what conditions a product-oriented versus a process-oriented network would be more effective. Ferdows (1989, 1997b) and Vereecke et al. (2006), among others, suggest that plants in a network have different strategic roles which define their relationships to headquarters and to each other, as well as to other functions in the firm (especially research and development, procurement, and distribution) and to other entities outside the firm.

A subgroup of this stream of research uses the network—as opposed to plants within the network—as the unit of analysis (Shi and Gregory, 1998; Colotla et al., 2003; Vereecke et al., 2006; Ferdows, 2008; De Meyer and Vereecke, 2009). An important premise here is that intra-firm manufacturing networks can develop capabilities that go beyond the sum of plant-level capabilities. On the other hand, Lampel and Giachetti (2013) suggest that there is an inverted U-shaped relationship between the firm's international manufacturing diversification and its financial performance—i.e., performance declines beyond a certain point because the production network becomes too complex to manage. This stream of research suggests that a plant's performance should be measured by its effect on the firm's production network. In other words, measuring the performance of a plant without explicit consideration of its effect on the performance of the rest of the firm's production network (or at least the subnetworks that are directly affected) can be misleading.

These three streams of research stress the importance of taking a network perspective for managing production. However, while they offer useful insights into the potential benefits of taking this perspective, they do not suggest many tools for how to do that. Our model is a step in closing this gap. It is only one of several models that managers need to manage their global production networks. Our model can be used as a tool to perform a high-level analysis of the network systematically. In the following sections, we first describe the model and then use it to analyze the production networks of five multinational companies. We illustrate how the model serves as a useful tool for auditing global production networks and spotting potential strategic anomalies in them.

3. The model

The model is based on a framework proposed by Ferdows (2008), suggesting that a firm's plant network can be delayered into a set of subnetworks based on a) complexity and proprietary design of the products they produce and b) complexity and proprietary design of the processes they use to produce them. The framework is depicted in Fig. 1. It can be applied to analyze the global plant network of a division, a business unit or an entire company—depending on the level of granularity desired.

3.1. Subnetwork positions

As shown in Fig. 1, subnetworks can fall in one of the four quadrants based on the complexity and proprietary knowledge embedded in their products and production processes: the rooted subnetworks, the footloose subnetworks, the process innovation networks, and the low investment subnetworks. As we discuss below, the position of the subnetwork in this framework provides strong indications about its manufacturing mission and the level of resources it needs to accomplish it.

Top-right Quadrant — Rooted Subnetworks: Subnetworks in the top-right quadrant produce products with unique and often advanced designs. For example many plants in a company like Intel or Huawei are in such subnetworks. Their products usually need to be supported by continuous research and their advanced and rather sophisticated process technologies must also be frequently upgraded (Vereecke et al., 2006; De Meyer and Vereecke, 2009; Ferdows, 2008; Pisano and Shih, 2012). They need highly skilled operators and technicians as well as access to expertise and knowledge in their industries, resources that are usually found more easily in industrialized countries. These subnetworks often contain several plants that are considered as “centers of excellence” in the company, signifying that they develop new production capabilities that can be shared with other plants.

Plants in these subnetworks need stability. Building deep expertise in both product and process technologies takes time and, because the knowledge behind this expertise is usually in tacit form, much of it must be developed locally, in interaction between engineering and production (Pisano and Shih, 2009, 2012). Therefore, these subnetworks must be “rooted”—i.e., their plants should stay in place for long periods. Offshored plants in these subnetworks are among the best candidates for reshoring and outsourced production of products that fall in this quadrant are among the best candidates for insourcing.

Bottom-left Quadrant — Footloose Subnetworks: These subnetworks produce commodity-type products using production processes that are standard in the industry. For example, many subnetworks of plants producing products for IKEA, Dell, Levi's, or Toys R Us, are in this quadrant. The critical mission for these plants is usually minimizing production costs while meeting required quality and delivery specifications; hence, being located in low-cost environments would generally be advantageous for the plants in these subnetworks. Since the knowledge for producing commodity products is usually codified and well understood in the industry, it is relatively easy to transfer production from one plant in these subnetworks to another or even outsource it to a third party (Ferdows, 2006). This makes the plants in these subnetworks “footloose”. The ultimate footloose network sources all its products from suppliers at arm's length. Hong Kong based Li and Fung, with no factories of its own, sources many products for large retailers from such networks.

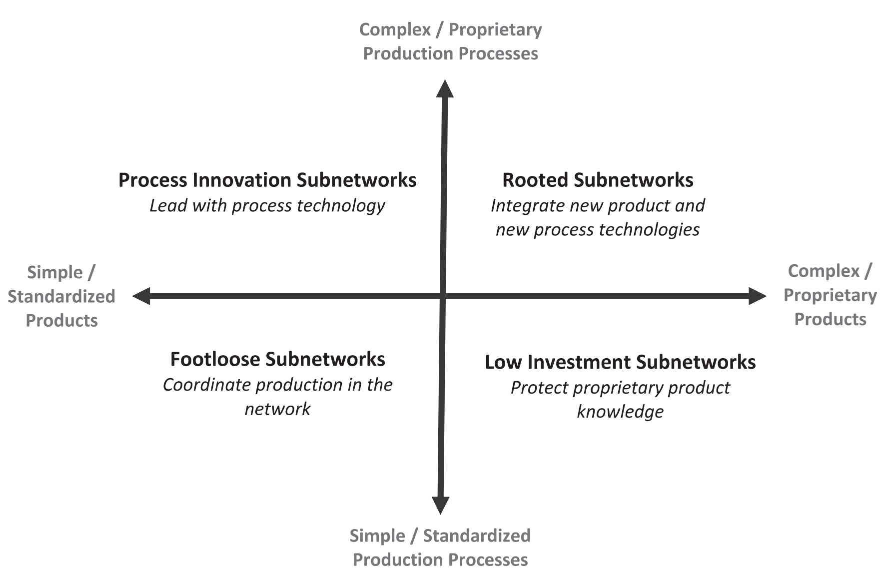

Fig. 1. Framework for gauging plant subnetworks.

Top-left Quadrant — Process Innovation Subnetworks: Subnetworks in the top-left quadrant use sophisticated and proprietary production processes to produce rather simple and commodity-type products. For example, Nucor, a US based steel company, produces basic steel products (like flat rolls) using advanced processes. Another example is Lego, the Danish toy producer; Lego uses highly sophisticated molding and packing processes to produce its famous simple looking "bricks". The critical mission for these subnetworks is process innovation, which can be easier if some of the plants in these subnetworks are in the sophisticated environments usually found in industrialized countries. Since there is inevitable leak of best practices, a proprietary process is not likely to remain proprietary after a few years, and if these subnetworks do not keep up with process innovation, they are likely to slip to the bottom-left quadrant or even be closed. It is not easy to stay in this quadrant, especially in a position far above the diagonal.

Bottom-right Quadrant — Low Investment Subnetworks: Subnetworks in the bottom-right quadrant make mostly proprietary products using production processes that are standard in the industry. In general, plants in these subnetworks are not a source of competitive advantage for the company. Many subnetworks in the pharmaceutical industry are in this quadrant. Subnetworks producing products like Louis Vuitton bags or Bose headphones are also often in this quadrant. The usual mission for these subnetworks is to supply reliable quality and quantity of products at the right time and place. Another critical mission is to reduce the risk of leakage of the proprietary product knowledge. For example, even if these subnetworks include plants by subcontractors and suppliers, the company often controls or owns many of the special tools, molds, or machinery for making its products. Still, there is often a high emphasis placed on maintaining confidentiality. This may motivate the company to keep many plants in these subnetworks in countries with reliable and enforceable laws, even if they are in a high-cost environment, to mitigate the risk of losing control of its brand image and proprietary information. Mitigating this risk can be a strong motivation for *reshoring* the offshored plants in this quadrant.

Note that this framework is different from the well-known "product-process matrix" suggested by Hayes and Wheelwright (1979). The axes here, for both product and process, measure complexity and level of proprietary knowledge, whereas in the product-process matrix the measure for process is pattern of flow (from "job shop" to "flow shop") and for product is the typical batch size (from "one-of-a-kind" to "very large batches"). To illustrate the difference, consider two production networks that produce cell phones in very large quantities, one making the latest smart phone deploying proprietary production processes and the other a low-cost simple model using standard and commonly available production processes. They would be on the same position on the product-process matrix (large batch size, close to continuous flow) but on opposite ends on this framework (the network for the new phone on top right and for the old one on bottom left).

3.2. Subnetwork stability and competency

A typical global production network can be delayered into subnetworks that may be anywhere on this framework. A particular plant can belong to more than one subnetwork if it produces different products or uses different production processes with varying levels of complexity and proprietary knowledge. To be "congruent", a subnetwork should normally be on the diagonal (Ferdows, 2008), as shown in Fig. 2. The logic behind this stems from the usual industry dynamics suggesting that with passage of time both products and production processes in an industry normally move from being proprietary and complex to becoming commonly available and standardized.

Being on the diagonal is not sufficient for being congruent. A congruent subnetwork must also have the appropriate level of competency to achieve its manufacturing mission. Rooted subnetworks need high levels; footloose subnetworks low levels. We will describe how to assess and measure the competency of a subnetwork later, but briefly we are defining it essentially as the average of the competencies of the plants that comprise the subnetwork. The competency of each plant is gauged by observing the extent of activities beyond basic production that are carried out at the plant, especially activities related to improvement of products and processes, development of new products and new processes, and working with suppliers, customers and others outside the plant.

Fig. 2 illustrates a stylized pattern of congruent subnetworks.

The template shown in Fig. 2 can help senior executives spot potential strategic anomalies or a lack of congruency. A red flag is raised when a subnetwork is on the diagonal but its average competency is clearly smaller or larger than suggested by this pattern, indicating that the company may be misallocating its resources. Another red flag is when many plants in a subnetwork in the bottom-left quadrant (i.e., a footloose subnetwork) are in high-cost environments. Most likely, these plants are fighting for

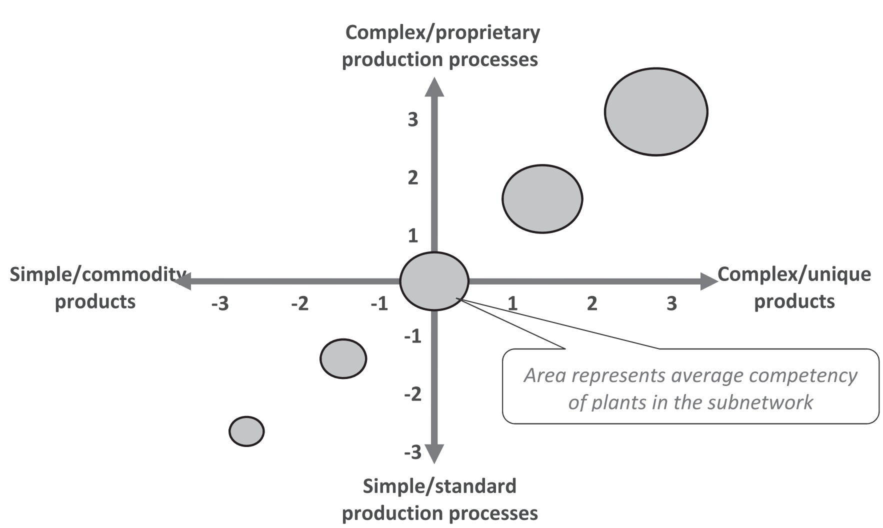

Fig. 2. Expected pattern of congruent subnetworks.

survival. They need attention in the short run, and may need radical changes in the long run.

Subnetworks that are off diagonal should also raise questions. Are they in such positions due to deliberate strategic choices or gradual movements that have not been visible? For subnetworks in the top-left quadrant, are they there because the company is competing through unique production processes or because the plants in these subnetworks are still using sophisticated production processes for producing products that are no longer complex or unique by industry standards (i.e., these subnetworks have gradually moved horizontally to the left of the diagonal)? Conversely, the subnetworks below the diagonal, are they there because their plants are lagging behind in upgrading their production processes for producing the sophisticated line of products that has been assigned to them (i.e., they have moved to the right on this framework) or the company wants to use standard and widely available production processes for producing rather complex and proprietary products?

3.3. *The slippery slope from rooted to footloose*

If the model is applied periodically, it will also allow tracking the changes in the position of subnetworks over time. It alerts the management to watch for the potentially slippery slope from rooted to footloose networks. In recent years, many subnetworks have been moving down the diagonal as a consequence of aggressive outsourcing or offshoring. The process is usually gradual and every step is justified by savings that can be easily quantified. But in many cases if the *total* cost of these actions, including their less quantifiable and long term consequences, are considered, they may not be justified. Furthermore, a series of these incremental decisions often limits the range of strategic options for the company, putting its once rooted subnetworks on a slippery downward slope which can become quickly irreversible (Ferdows, 2008).

This point is receiving more attention in the last few years, and has started a drive to reshore and insource production that had been offshored or outsourced (De Treville and Trigeorgis, 2010; Tate, 2014; Tate et al., 2014). However, moving up the diagonal is much more difficult than moving down. It is difficult to rebuild a rooted network because competencies accumulated over years may have been lost in the interim. Our model can provide early warning to allow the management stop the slide before it is too late.

In sum, our model can be used as a tool for both assessing current *congruence* of the subnetworks and, when applied periodically, detecting whether the subnetworks are evolving in the right direction. It does not *optimize* the network nor *prescribe* a design for its architecture. It is a powerful instrument to simplify the analysis of a complex network and spot any strategic anomalies that deserve management attention. It can also suggest, in broad terms, whether different plants are in right places—for example which of the plants in high cost environments are likely to thrive and in the long run which ones are likely to be in vulnerable positions. We illustrate how our model helps answering these questions in the next section by applying it to analyze the production networks of five companies.

4. Operationalizing the model

This section shows both how the model can be operationalized and applied in practice. The five companies illustrate the range of analysis that can be performed by applying our model. All five companies had their headquarters in Europe, although two were autonomous European divisions of large US multinational companies (and in their cases, the term "company" refers to the division.) We collected our data from internal company documents and interviews with senior managers in late 2009 and early 2010. The interviews were semi structured, each taking about two hours and usually with two or more senior manufacturing managers in the company.

Our analysis consisted of three steps:

I. Determining the number of subnetworks in the company's global production network:

First we identified major product groups sold by the company, including those not produced by the company itself. This was usually an easy task for managers. Next we compiled the list of all plants in the company's global production network (including the partners and suppliers producing finished products for the company) and the location of these plants. The third step here was to identify which plant produced products for which product group. The three steps defined the products and plants belonging to each subnetwork.

II. Gauging the positions of subnetworks

The next task was to position each subnetwork on the framework shown in Fig. 1. Placing it on the horizontal axis required assessment of the complexity and the level of proprietary knowledge of the representative product in the subnetwork, and placing it on the vertical axis required assessment of the complexity and the level of proprietary knowledge of the processes used in producing the representative product. We used 7-point scales (from -3 to $+3$, with zero denoting the "average" in the relevant industry) to gauge these positions. These scales are described in Appendix A. There was generally a strong consensus among the managers in assigning these scores for each subnetwork.

III. Gauging competencies of subnetworks

We used the activities that were carried out at the plant site as the proxy for the competency residing in that plant, and used a 9-point scale to measure it: 1 signifying that the plant did essentially only basic activities that were required for production, and 9 signifying that the plant was engaged, in addition to production, in extensive process and product development, strong linkage with research and development, procurement, distribution, and final customers. This scale is described in Appendix B.

The next step was to compute the competency of each subnetwork. As mentioned earlier, we took the average of competencies of each plant in the subnetwork and we made a minor adjustment to account for dispersion of competencies among plants in the subnetwork. The details are explained in Appendix C.

4.1. *Analysis of the five cases*

We present the analysis for the five companies below.

4.1.1. *Company A — luggage*

This company sold a large variety of luggage, ranging from simple bags, made from standard fabrics by simple machinery to sophisticated suitcases made from composite materials using advanced technology and custom-made machinery. Our analysis resulted in five congruent subnetworks shown in Fig. 3.

There are no red flags. All subnetworks seem to be congruent: they are on the diagonal with appropriate levels of competency. For example, subnetwork A1 is clearly rooted with sufficient competency. Managers mentioned that the company was developing new process technologies in several of the plants in this subnetwork. In

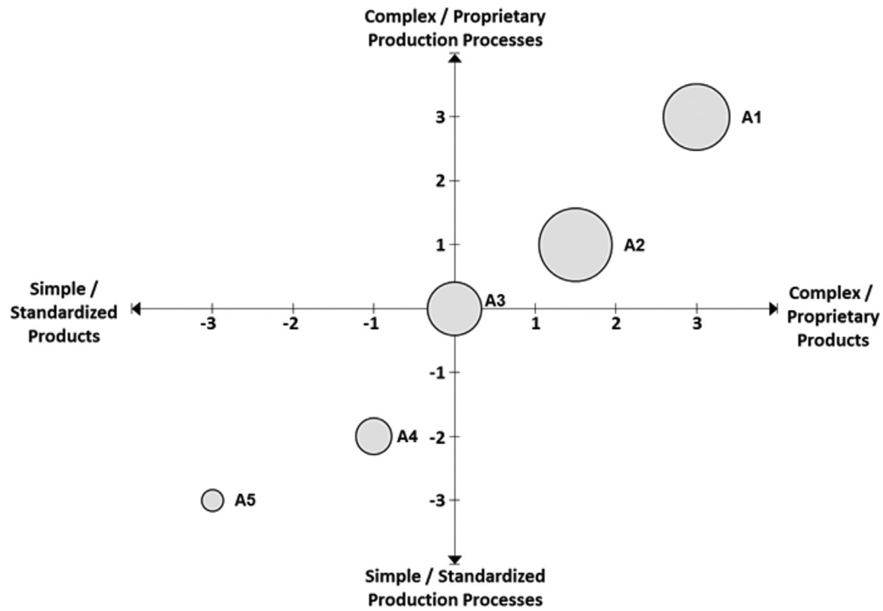

Fig. 3. Subnetwork map for company A.

contrast, subnetworks A4 and A5 produced many simple products, some of which had been outsourced (hence the smaller size of the circle, especially for subnetwork A5).

Were the plants in each subnetwork in right places? The answer, on the whole, was yes. Plants in subnetwork A1 were all in Europe, with the most important one close to the company headquarters in northern Europe. Given the patented and radically new products they produced and their sophisticated production methods and proprietary machinery and technology, they seemed to be in the right locations even though they were in high cost environments. On the other hand, most products in the footloose subnetworks A4 and A5 were sourced from suppliers in low-cost locations in East Asia.

The only minor question was why subnetwork A2 had a slightly higher level of competency than subnetwork A1. According to our model it should not. Management explained that this was due to a deliberate strategic choice. The company was becoming the dominant player in the market for the product line made in this subnetwork (only one competitor was left) and did not want to risk any disruption of production at this time; hence it was using its most sophisticated plant to produce this product line.

4.1.2. Company B — consumer plastic products

This company made a large variety of injection molded plastic products for consumer markets. Fig. 4 shows the subnetwork map for this company. The very small circle of subnetwork B4 denotes that the entire production for this line had been outsourced, resulting in a competency score of near zero.

Subnetworks B1 and B2 in the upper-left quadrant seemed to be congruent. Subnetwork B1 consisted of two plants in high-cost regions of Europe and US; these two plants were also a part of the B2 subnetwork, but B2 also had two other plants in lower-cost regions in Southern Europe and Africa which did not have the same level of competency (hence a smaller circle for the subnetwork fitting its position on the framework). On the whole, the four plants in B2 seemed to be in right places to thrive.

However, subnetwork B3 raised a flag. Why did it have almost the same competency level as B2? The answer was that the company was currently underutilizing the competencies of the five plants in this subnetwork. But why? Why had the company not allocated more sophisticated products for more demanding customers to these plants and outsourced the simple products they were currently producing? Several managers felt that this was a reasonable question and decided to reexamine the strategy for this subnetwork—either move it to the right (i.e., allocate more sophisticated products to it) or transfer some of the resources from these plants to subnetworks B1 or B2 (i.e., reduce the size of the circle).

The extreme low competency of subnetwork B4 also attracted management's attention. These products had been outsourced because they required processes that were not found in company's own plants (e.g., they needed materials like metal that the company did not process or blow-molding instead of injection molding which the plants were not equipped to do). While in recent years the volume of these products had gradually increased, their production strategy had not changed. Another question for the managers was whether it was time to reexamine the strategy for B4 and consider moving it up the diagonal.

4.1.3. Company C — steel products

This company made many kinds of steel products for industrial markets in 18 plants located in 10 countries. Its global network could be delayered into three subnetworks as shown in Fig. 5. Subnetwork C1 produced extremely thin cables that had to be made to exacting specifications by sophisticated and proprietary production processes; subnetwork C2 produced slightly less complex products that also required advanced and efficient production processes; subnetwork C3 produced essentially commodity products that could be processed on standard machinery widely available in the industry.

Although the three subnetworks were positioned fairly close to the diagonal, they did not seem to be congruent: Competencies of subnetworks C1 and C2 seemed to be too low and C3 too high.

Closer examination revealed that all three subnetworks had plants with wide ranges of competencies; the plants with very low competencies lowered the averages for C1 and C2 and the ones with very high competencies increased the average for C3. The primary reason for this was the strategy of setting up “satellite” plants close to major industrial customers. Most of these satellite plants were designed to carry out only basic production tasks,

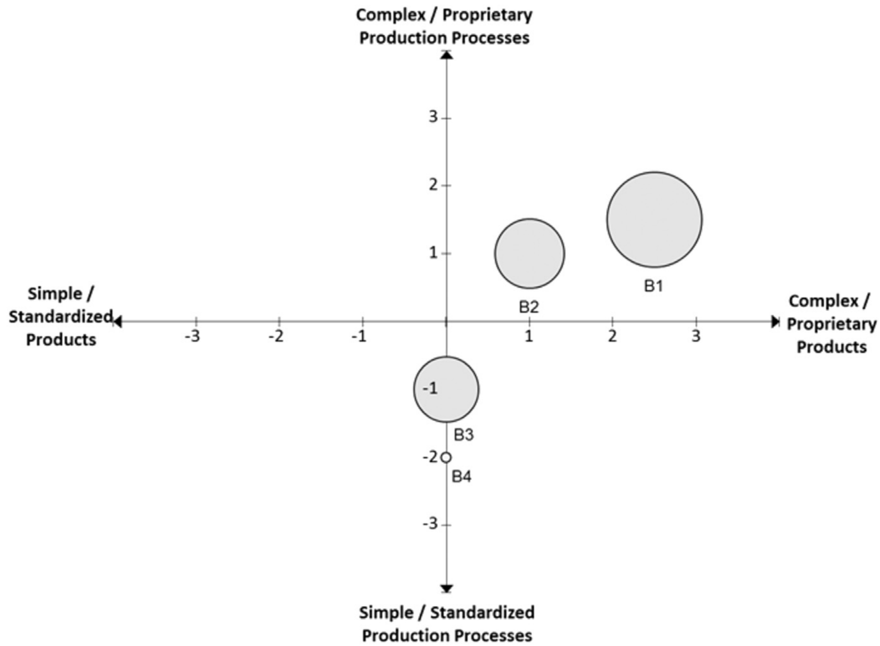

Fig. 4. Subnetwork map for company B.

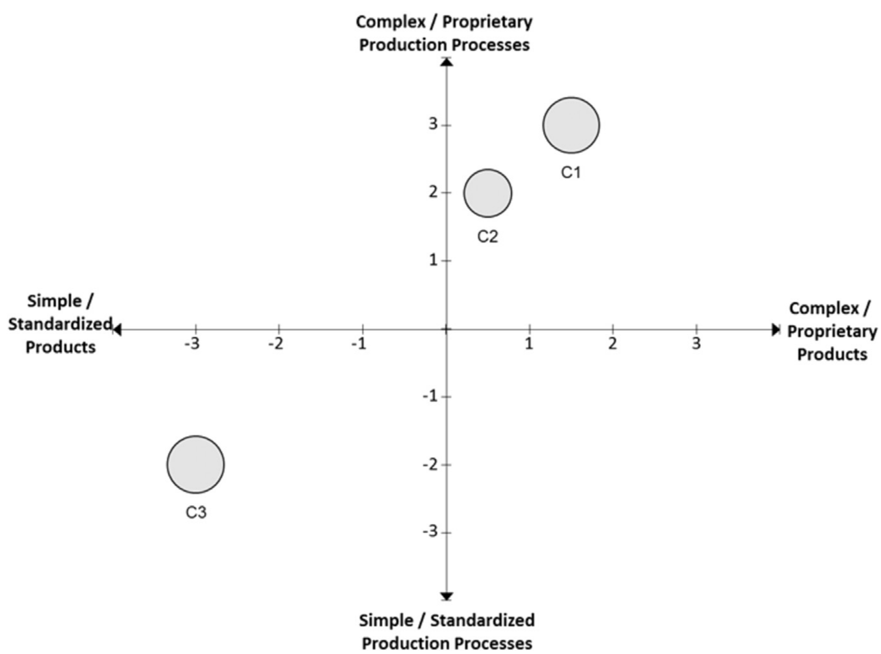

Fig. 5. Subnetwork map for company C.

hence scored very low for competency; they depended on a few plants with very high competencies for new processes and new products.

The similarity of the competencies of the three subnetworks raised fresh questions about this strategy. Should the company increase the competencies of at least some of the plants in subnetworks C1 and C2 that were located in highly advanced countries and expand their strategic roles from merely serving their local markets? In the ensuing discussion, managers identified two candidates for this move: one plant in Europe close to the company's headquarters and another one in Asia. These plants already had somewhat higher levels of competencies than many others and could increase them further. They could strengthen their linkages with the company's R&D department (particularly the plant in Europe), major suppliers of production equipment and material suppliers, and develop new process technologies for the entire company. If they went ahead with this plan, the competencies of C1 and C2 subnetworks would increase, making them move closer to being congruent.

The subnetwork C3 was different. Why were these simple products produced in some of the company's advanced plants in high-cost environments, especially when production of these products could be outsourced? The answer, as a senior manager explained, was that “We have a big fear to put our name on a product if we don't control the process, and we have sufficient production capacity in these plants to make these simple products. (…) It does imply, however, that the [production] cost of this product is *too* high just because we make it in expensive plants with a lot of staff."

While this explained the reason for this anomaly, it prompted a discussion of a change in strategy for this product line. Given the competencies of the plants in subnetwork C3, especially those located in high-cost environments of Europe and US, should the company upgrade this product line from commodity to a more specialized line of products? This strategy promised to be more sustainable in the long run than the present one. As a senior manager stated, "This plan would be consistent with our company's desire to be the market leader in this product line. It would require technological effort, and we will have a team to look into developing new processes which will distinguish us from competition." If this plan was implemented, subnetwork C3 would move up the diagonal in our model, and would become more congruent.

4.1.4. *Company D — food products*

This company produced a variety of food products in 42 plants in 22 countries in Europe, US, and Asia. Some of the plants produced raw materials for other plants while others produced basic products for both internal and external customers, and some did finishing and packaging. Fig. 6 shows the subnetwork map for this company.

Subnetworks D2 and D3 did not seem to be congruent: they were off diagonal and did not have appropriate levels of competencies; even D1, while on the diagonal, seemed to have inadequate level of competency. Why? The unique structure of the global production network in this company was a part of the explanation. Almost all product and process developments in this company had been centralized in one plant close to its headquarters. Most of the other plants had low competency scores and were essentially dependent on this headquarter plant for all services. It was a deliberate choice by the company to centralize product and process development in order to make products interchangeable, to establish global quality standards across the plants and to optimize efficiency in all its plants.

Similar to Case C, this raised the question of whether the policy of concentrating the company's technical resources for production innovation in one plant and leaving the rest at low competency levels was appropriate and sustainable. Managers mentioned that the product group produced by subnetwork D1 had recently come under pressure from competitors, forcing a move towards commoditizing the product, and as a consequence, putting the subnetwork D1 on a slippery slope to move down the diagonal. The explanation for why subnetwork D3 was off diagonal was that the products produced by this subnetwork used production processes that were fairly standard in the industry, but the products they produced were fairly unique relative to competitors' products because of their special shapes and packaging.

Subnetwork D4, in the lower left quadrant, although not exactly on the diagonal, seemed to be congruent. But high dispersion of competency levels among plants in this subnetwork raised a question. Closer examination revealed that most of these plants were located in low-cost environments close to sources of raw materials, and had low levels of competency. Only two plants in this subnetwork had high levels of competency. They were both in Northern Europe and carried out process engineering and optimization for all plants in this subnetwork. Given this strategy, plants in this subnetwork, both those in low-cost and high-cost environments, seemed to be in right locations.

4.1.5. *Company E — textile*

This company went bankrupt in 2012 but we have included it here to show the predictive capability of our model. In 1995, this company had six plants, five of which were in high-cost countries. Since all plants were producing basic products with standardized processes, they could be placed in one subnetwork as shown in Fig. 7a. Fifteen years later, the company had only one plant left, located in northern Europe. By then, it produced two different lines of products: one still consisting of the basic products, which could easily be produced by other firms; the other consisting of fairly unique products requiring a proprietary production process. Even though there was only one plant, according to our model this company was operating two clearly different "subnetworks", as shown in Fig. 7b.

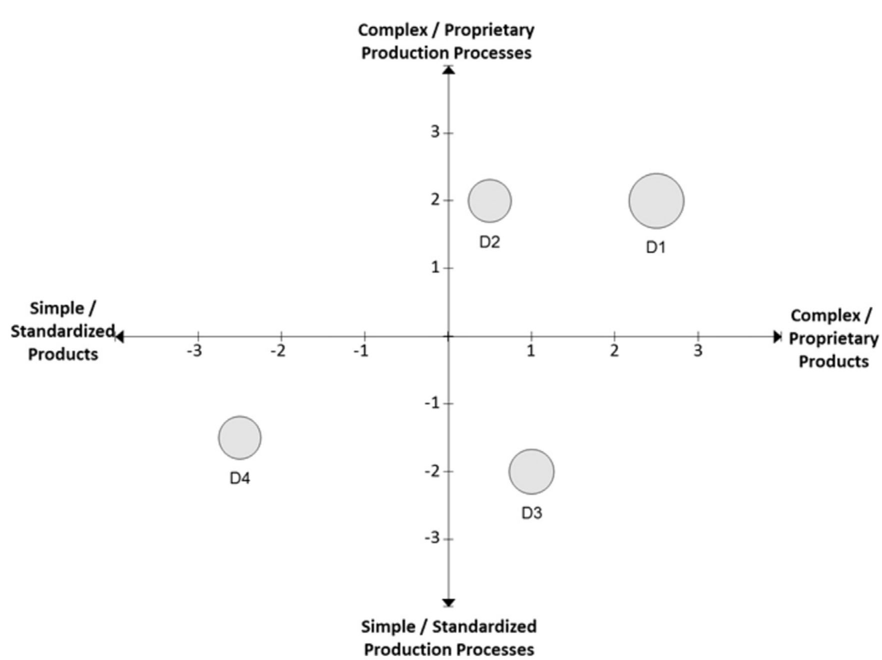

Fig. 6. Subnetwork map for company D.

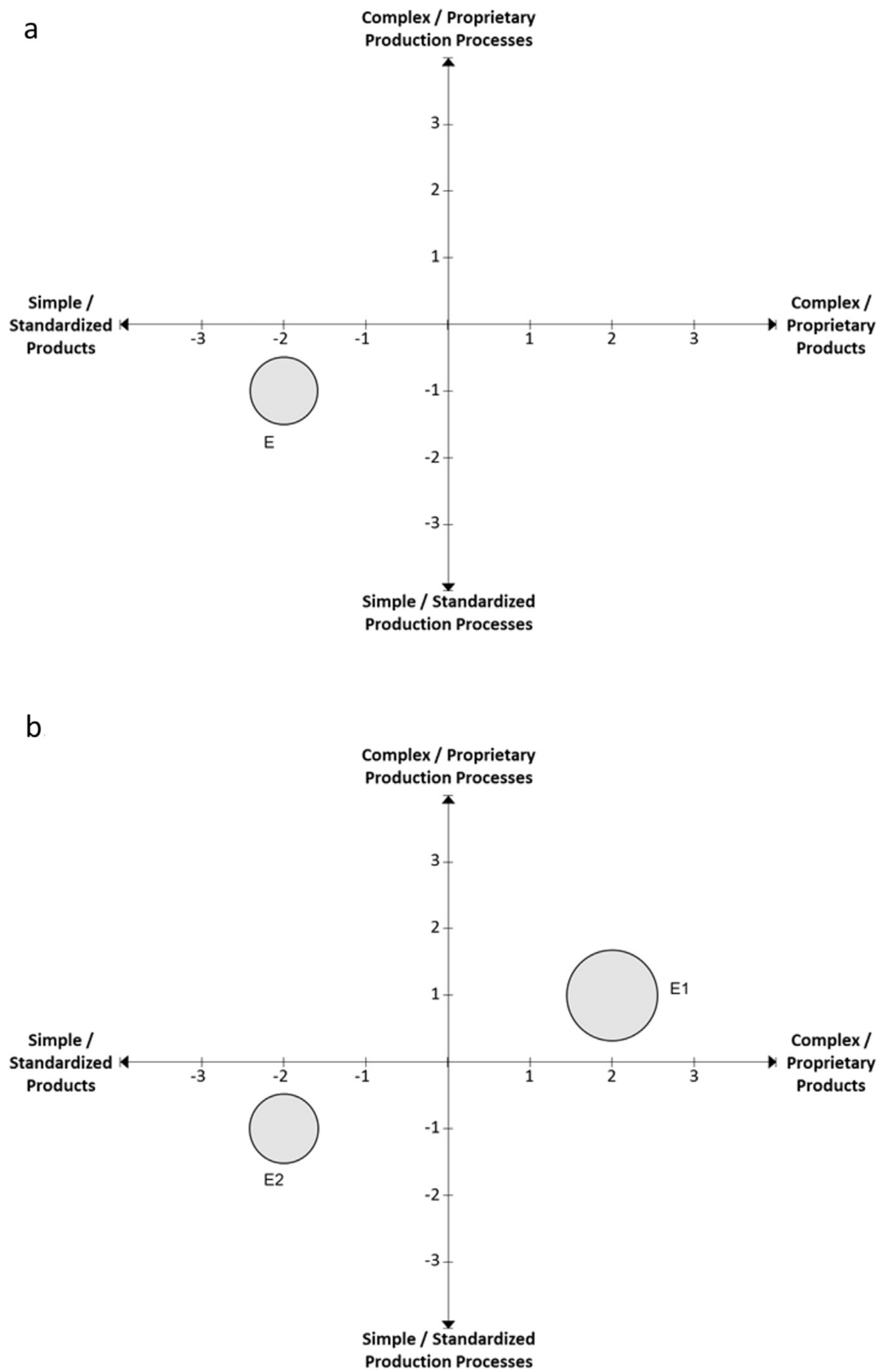

Fig. 7. a. Subnetwork map for company E in 1995, b. Subnetwork map for company E in 2010.

Back in 1995, this company's single subnetwork (E in Fig. 7a) was off the diagonal and, since it was offering products that were being commoditized, it was under pressure from competitors in low-cost environments. This subnetwork was on a slippery slope that was moving it further off the diagonal to the left. There were two rather obvious options to get closer to the diagonal: move *down* by offshoring or outsourcing production to low cost environments or move *right* by offering more sophisticated products. The company could have done both by offshoring or outsourcing production of simple products and upgrading capabilities of its plants in the industrialized countries to produce the specialty products. However, the company did not move decisively in either direction. By 2010, it had introduced a new line of specialty products but had closed five of its six plants. The new product line had to be produced in the remaining plant, but the volume was not sufficient to fill its capacity and the plant had to use almost half of its capacity to produce the simple product line (hence the two subnetworks E1 and E2 shown in Fig. 7b). It should have been clear that such an unfocused plant was likely to run into problem.

Perhaps if we had applied our model to analyze the production network of this company in 1995, when the company still had six plants, it could have prompted a timely discussion of the problems and the urgency of finding a viable solution and preventing the bankruptcy.

4.2. Spotting strategic anomalies and lack of congruency

As the discussion of the five cases show, the utility of our model is in spotting potential strategic anomalies or lack of congruency. While the model does not prescribe solutions, it allows performing a high-level audit to flag areas that need attention and possibly new strategies. To summarize:

a) An off-diagonal position of a subnetwork on the framework (shown in Fig. 1) suggests a possible anomaly in the allocation of products to plants; if this is not a deliberate strategic choice, it needs attention.
b) An unusual size of the circle representing the average competency of the subnetwork (compared to the pattern shown in Fig. 2) suggests lack of fit between subnetwork's capabilities and its manufacturing mission. The subnetwork may have insufficient or excessive levels of resources to meet its mission.
c) The position of the subnetwork in different quadrants (shown in Fig. 1) signals a gentle alert about potential long term problems with the locations of its plants. If many plants in a subnetwork in the bottom-left quadrant (footloose subnetworks) are in high-cost environments, the subnetwork is likely to run into problems in the long run. However, this would not be a concern if the subnetwork happens to fall in the top-right quadrant (rooted networks).

Likewise, a subnetwork that is *deliberately* positioned in the top-left quadrant (process innovation subnetworks), may need plants in locations close to rich "industrial commons" (Pisano and Shih, 2009) to facilitate access to highly skilled technicians, laboratories, suppliers, and key customers that help the subnetwork maintain its advantage in process technology. Emergence of pockets of sophisticated industrial commons around the world, especially in East and South Asia, is prompting a fresh reexamination of where the plants in these subnetworks should be ideally located.

Finally, for the subnetworks in the bottom-right quadrant (low investment subnetworks), for which reliability and protection of proprietary product information are often critical missions, plants in risky locations should raise a flag.

5. Conclusions and future research

We need a new direction for research to cope with the growing complexity of today's global production networks. Rather than continuing to build increasingly more elaborate optimization models—which seems to be prevalent particularly among scholars in operations management—we need models that can *reduce* the complexity of managing these networks. The optimization models are of course useful for solving the *tactical* problems in these complex networks (for example, how to reduce logistics costs for supplying a particular market from alternative plants). But they are becoming less useful for answering the *strategic* questions about the network. Models for optimizing the strategy for a global production network would need to make many assumptions, quantify a large number of intractable qualitative variables, and often rely on complex algorithms. The result may be a sophisticated model but of questionable practical value for those who actually design and manage these networks.

Instead we suggest providing more tools for managers to reduce the complexity of these networks. Ironically, the simpler the tool, the better. It seems that when faced with a complex problem, managers prefer simple tools as opposed to complicated ones. We consider the model we present in this paper to be an example of how a simple tool can help managers as they tackle a complex problem.

Our approach is to decompose the complexity into simpler parts. The model delayers a complex plant network into a set of subnetworks that are easier to analyze, specifically assess whether they are *congruent*—i.e., the subnetwork has an appropriate manufacturing mission and the requisite level of competencies (embedded in the plants that comprise it) to accomplish that mission. We utilize visualization to increase the appeal and ease of use of the model, particularly for practitioners. Visualization helps spotting strategic anomalies, or lack of congruency, quickly and highlights the areas that deserve management attention. The ease of use makes the model a practical tool also for periodic audit of the subnetworks and for tracking their evolution through time.

Like any new model, ours needs to be further refined, tested and extended. We see five areas for future research directly related to this model:

First, there is a need to test the relationship between congruency and long term performance of the subnetwork. This would require, ideally, a longitudinal study of a large sample. Such an investigation would not be easy but its findings can be consequential. A stream of research in the last few decades has investigated whether focusing a factory actually improves its performance; we need a similar approach for investigating the relationship between the congruency of a subnetwork and its performance.

Second, it would be interesting to delve deeper into management of subnetworks in different quadrants in the model. What are the critical skills that are needed to manage a "rooted subnetwork" and how are they different from those needed to manage a "footloose subnetwork" or a "process innovation subnetwork"? What are the best key performance indicators for the subnetwork in different positions on this framework? There is much interesting work to be done in analyzing how to manage the competencies in the different subnetworks or, generally, determining what kind and how much attention they need from top management.

Third, it would also be interesting to map different moves on this framework and investigate their ease or difficulty. For example, the slippery slope from rooted to footloose subnetwork suggests that it is easier to move down the diagonal than up. If this is empirically validated, then senior management should be particularly careful if they detect a downward move.

Fourth, an intriguing question is whether this model can provide an indication of the role of manufacturing in the firm's business strategy. For example, does presence of more congruent subnetworks in a firm's global production network suggest a more important role for manufacturing in the firm's business strategy? Or, does presence of many subnetworks in the low investment quadrant (bottom right in Fig. 1) suggest a low role of manufacturing in the firm's strategy? Or, if in two competing firms, one has more *congruent rooted* subnetworks in its global production network than the other, does that indicate a higher role for manufacturing in its corporate strategy? There are many such questions that can be investigated.

Going beyond our model, we suggest further research into developing new approaches for reducing the complexity of global production networks. This is important because managing them is becoming dauntingly complicated and reversing an undesirable change in these network is often a long, expensive, and difficult process. Sometimes it becomes irreversible, limiting the strategic options for the company. We need more tools like the one presented in this paper to help managers spot anomalies quickly and systematically, and take corrective action.

Appendix A. Measures for product and process characteristics

We used a 7-point scale to gauge the complexity and proprietary information intensity of the products and processes. For assessing the product characteristic, using the general guideline shown in Table A1, managers in each company assigned a score between −3 (a product group that was clearly a commodity in the industry) and +3 (a product group that was clearly proprietary and complex relative to what was available in the industry). In order to obtain consistency in the scoring across the cases, the interviewees were asked to provide (in addition to the scores) evidence that illustrated their opinion about the products and the processes. In almost all cases, we provided guidelines for how to define the relevant industry and interpret different ratings on this scale.

Table A1
Scale for assessing product characteristics.

Commodity products	Complex and proprietary products
Very infrequent introduction of new products	Very frequent introduction of new products
Very few marginal changes made in existing products	Very frequent major changes in product, differentiating it from competitors products
Product design is basically simple and well understood in the industry	Complex product design
Standard and widely available raw materials and components	R&D-intensive materials and components
Few variations and choice of features, shapes, colors, materials, etc.	Many variations, choice of features, complex shape, special materials, etc.

To assess process characteristics, we asked managers in each company to assign a score between −3 and +3 to indicate the level of complexity and proprietary knowledge embedded in the production processes of the typical plant in each subnetwork. Similar to measurement of product characteristics above, we asked for supporting evidence and provided advice for how to interpret different ratings on this scale. The general guideline is described in Table A2.

Table A2
Scale for assessing process characteristics.

Standard production processes	Complex and proprietary production processes
Production know-how is highly codified and widely available in the industry	Production know-how is mostly in tacit form
Production can be easily and quickly transferred from one plant to another	Level of experience can differentiate the process between competitors
Changes in production processes are very infrequent	Transfer of production from one plant to another is difficult
Process innovations are rare	Process innovation is frequent and highly emphasized
Most process technologies are developed outside the firm	Significant new process technologies are developed in-house
Equipment and machinery are highly standardized	Significant portion of equipment and machinery are designed in-house

Appendix B. Measures for competency

We used a 9-point scale, shown in Table B1, to measure the competency of each plant. This scale is based on the work done by Ferdows (1989), Vereecke and Van Dierdonck (1999, 2002) and Vereecke et al. (2006).

Table B1
Scale for assessing plant competency.

Level of competency	Score
The main goal of the plant is “to get the products produced”. Managerial investment in the plant is focused on running the plant efficiently.	1
	2
Plant has sufficient internal capabilities to develop and improve its own components, products and production processes	3
	4
Plant is a focal point in the company for the development of specific important components, products or production processes	5
	6
Plant develops and contributes knowhow for the company	7
	8
Plant is a “center of excellence”, and serves as a partner of headquarters in building strategic capabilities in the manufacturing function	9

Appendix C. Computing competency of subnetworks

We computed the competency of each subnetwork by taking the average of the competencies of plants in it. If production of a product had been completely outsourced to arms-length suppliers, we used a score of 0 for the competency of the “plant” that produced those products (because the competency for making those products resided outside the firm). However, for those outsourced products that the relationship with a supplier or contractor went beyond arms-length to collaboration in tooling, customization, design and process improvement, we assigned a higher score up to 1.5. If in a subnetwork, some products were produced in-house and some had been outsourced, we took the weighted average (by the proportion of production volumes) of the average competency of company's own plants in the subnetwork and the average competency for the outsourced products in this subnetwork.

We also made minor adjustments to reduce the effect of dispersion of levels of competencies among plants in the same subnetwork. We wanted to differentiate between two subnetworks for which the weighted average of competencies of their plant were the same (say 5) but one consisted of plants with fairly similar levels of competencies (say between 4 and 6) and the other of plants with very different levels of competencies (say between 1 and 9). We wanted to make a minor adjustment in the scores to make the weighted average of the former subnetwork to be slightly higher than the latter (arguing that the combined competencies of the plants in the former subnetwork was likely to be slightly more than that of the latter). In the five cases, this adjustment had negligible effect for most and only a small effect for a few subnetworks. *(We used a technique similar to calculation of the "Gini Coefficient" for income inequality for gauging the inequality in competencies in plants in a subnetwork and used it to adjust the average. A technical note explaining the details can be obtained from the authors.)*

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