Situational Awareness as a Dynamic Capability in Innovation Networks[1]

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With distributed production networks, and the resulting distribution of innovation among participating firms, the need to organize and share knowledge across firms is essential. Networks which develop situational awareness through common or linked information systems and through coordination practices that foster information gathering, sense-making and sharing will be associated with a higher level of performance, and will be better able to meet the changing needs of the global market over time. Situational awareness built at the firm level and embedded into network practices will reflect a dynamic capability that will be a differentiator in network performance.

1. Introduction

The view of dynamic capabilities as organizational competencies has focused corporate attention on the importance of non-technical skill sets as a competitive driver. Nowhere is this more important than in cross-organizational innovation that occurs in networks of companies competing against one another. Such networked competition (Yusuf, Gunasekaran, Adeleye and Sivayoganathan, 2004; Sherer, 2003; Christopher, 2000) is replacing the more traditional transaction-based (Williamson, 1985) supply chain view. Yet individual companies are struggling with the underlying skill set needed to facilitate network competition.

In recent decades, many corporations that once spanned the traditional routines of the firm have been replaced by supply chains where some or nearly all of the production of goods and services is done by other firms. In 2006, for example, worldwide estimates for this outsourcing top $6 trillion U.S., with a 30% annual growth rate expected (CBC News Online, 2006). This trend has intensified due to several factors, including an emphasis on firm core competences (Prahalad and Hamel, 1990); modularization of design (Novak and Eppinger, 2001; Laseter and Ramadas, 2002); and increased global production capacity for goods and services combined with the information infrastructure to coordinate and/or provide them (Friedman, 2005).

Although the OEM is often the firm closest to the distribution channel or the end customer, it cannot compete without the innovative and production capabilities of its supplier network. In such a value stream, each firm adds value through distinctive capabilities where collaboration and coordination are achieved, in part, through common goals. Often shared goals are enabled by information technology and its ability to replace routine or redundant functions, anticipate communication needs, support collaborative planning and design activities, and forecast combined demand and consequent product flow needs across firms (Lanconi, Smith and Schau, 2003).

The auto industry is a prime example of how individual networks differ in both their approach to collaboration and coordination and in their success. Toyota, for example, values its suppliers' innovative capabilities and encourages the development of deep knowledge by

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investing capital in its suppliers and by encouraging common network knowledge through training and regular meetings (Dyer and Nobeoka, 2000). This can be contrasted to the Detroit model, particularly GM, which emphasizes cost cutting across its supplier network. The continuous downward price pressure limits a supplier's ability to invest in enhancing capabilities, and those suppliers that do have innovative solutions are not able to capture the economic rents that might otherwise be commanded through such innovation. Toyota's success cannot be disputed; nor can GM's troubling situation, particularly in the U.S., be denied.

At the heart of this network differentiation is knowledge development and sharing. This paper focuses on the innovation capabilities within networks, arguing that the distributed nature of invention, innovation and production creates unique knowledge acquisition and sharing needs. Here, the emerging importance of situational awareness in innovation networks is emphasized.

2. Firm and network situational awareness

The term *situational awareness* has its early genesis in the military, with more recent application to the intelligence analysis community. Its presence has been linked to performance outcomes among both individuals and groups (Endsley, 1995), and it is believed to be an essential component to effective leadership.

Situational awareness can be described most simply as "knowing what is going on around you" (Endsley, 2000), with an understanding of what is important being a necessary component of this knowledge. More formally, situational awareness is defined with respect to knowledge gathering and integration. Here, situational awareness is obtained by the "continuous extraction of environmental information, [and] integration of this information with previous knowledge to form a coherent mental picture in directing further perception and anticipating future events" (Vidulich, Dominguez and Vogel, 1994).

From an innovation perspective, situational awareness is important for individual firms and their associated collaborators in areas such as coordinating complex tasks, establishing mutual confidence, drawing attention to scientific details, developing a working understanding of new concepts, and synthesizing results into new knowledge (Sonnenwald, Maglaughlin and Whitton, 2004). The information gathering and sense-making are particularly relevant in the context of distributed innovation.

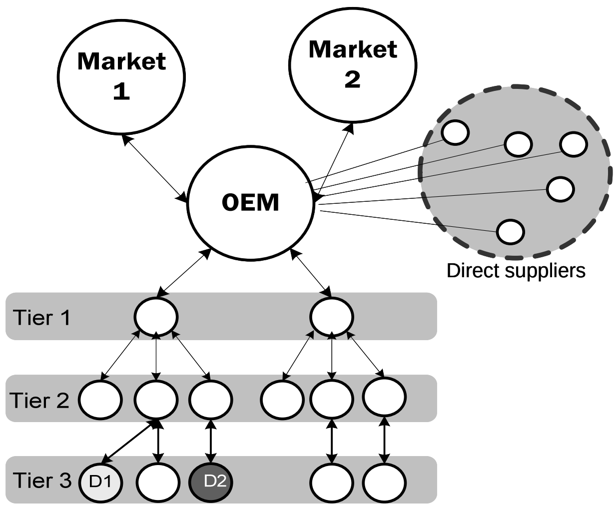
Endsley (2000) identifies three levels of situational awareness. Perception of cues (level 1) includes the identification of information which is both valid and relevant to the task or problem at hand. Comprehension of the current situation (level 2) happens when the human combines, interprets, stores and retains information. This information is often bundled into organized sets of highly selective information. The difference between level 1 and level 2 situational awareness is often described as the difference between being able to read words and reading comprehension. The highest level of situational awareness (level 3) happens when humans are able to take this selectively bundled information and predict future states.

Situational awareness is particularly important in environments where uncertainty is high and where there are frequent interruptions to the problem-solving routines. To achieve any type of situational awareness, then, implies that the human can search the environment for data, can identify which data are relevant and discard that which is not, and can then use this information to fully articulate the problem, identify alternatives, and predict consequences.

Human information processing is either data driven (bottom-up) or goals driven (top-down). In the latter instance, goals direct attention to information perceived in the environment. Conversely, in the case of data driven processing, perceived information can lead to the formation of new goals. Here there is a direct corollary to the way that innovation is derived – it can be formulated through technology push or market pull, bottom-up and top-down, respectively.

3. The realities of distributed innovation and production

With the advent of globalization, production and distribution take place on the world stage. Iansiti (1998) notes that individual technologies rarely define products. Rather, multiple technologies must be considered *with respect to one another* and with respect to the application into which they are embedded. Because of the complexity of modern products and because of the distributed production that occurs within the supply chain or network, selecting and refining technologies implies subtle interactions between the technical components, the product configuration, and on the organizational levels as



well.

Figure 1: Distributed production across an OEM-led supplier network

To facilitate discussion, Figure 1 highlights a supply chain model which is led by the original equipment manufacturer (OEM). This OEM is the route through which products reach markets 1 and 2 either directly or through the OEM's distribution channels.

The OEM coordinates production across Tier 1 and other direct suppliers. The Tier 1 firms then reach back into additional Tier 2 and 3 supplier firms to develop complex subassemblies to meet the OEM needs.

In this model, market knowledge flows from top to bottom – from the OEM through successive tiers. The OEM captures market knowledge and reflects this in its product configurations and product feature sets. As this market information flows downward, it becomes more and more specific – Tier 1 firms translate feature sets into product requirements which are then translated into feature dimensional specifications and tolerances for individual components produced by the Tier 2 and 3 suppliers.

Technical knowledge, on the other hand, frequently resides in the Tier 2 and 3 suppliers who are domain experts, where D1 and D2 in Figure 1 reflect different scientific and/or technical specializations. Within Tiers 2 and 3, experts in these firms have the explicit and tacit knowledge to recognize which technical or manufacturing solutions might be emerging to replace or enhance existing approaches. Moreover, these experts are often well-suited to estimate the likely timing of these possible developments. This knowledge gets implicitly embedded into the product offerings of the Tier 2 or 3 suppliers, and frequently helps the Tier 1 firms achieve OEM needs when these components are integrated into subassemblies and subsystems that in turn are linked in the OEM's product architecture.

Research in innovation, firm growth and profitability, and internationalization supports the information flows and model suggested by Figure 1. For example, Wolff and Pett (2006) studied more than 180 small to medium sized firms and found that those with a product development focus, driven by R&D investment and innovation, had a higher growth rate than those that did not. This suggests that firms that differentiate themselves with respect to technology capabilities and competencies are more valued by potential network partners than those that do not. This also implies the bottom-up specialization and knowledge flow argument.

Fang and Wu (2006) suggest that co-evolution of knowledge in what they call micro-evolutionary (within the firm) and macro-evolutionary (between firms) processes enhances innovation capability when this information can be shared across a network of firms.

Herein lies the critical challenge of distributed innovation. With knowledge distributed across the network of firms, how do emerging technology opportunities inform the development of products aimed at existing or predicted market gaps? Serendipity is not enough.

Consider for example a fuel cell automobile. The external shell may remain consistent, but the similarity to today's automobile quickly ends there. A PEM fuel cell, the most popular currently, runs with hydrogen. It is highly susceptible to contamination by carbon monoxide (CO) in particular which is a natural bi-product of hydrogen production by what is called a reformer. Currently sensors are used to detect the presence of CO, and algorithms that assess changing levels of CO help to protect the fuel cell's operation. Sensors are made by one company, fuel cells by another, cars by yet another. Moreover, the subsystems that translate electric energy into mechanical motion are significantly different than those used for today's combustion engine drive trains. Thus the challenge of the electric car is several fold, including:

(1) identify suitable sensors or develop non-CO sensitive fuel cells, two competing alternatives;
(2) change the way in which hydrogen is produced, an infrastructure issue;
(3) assess changes needed to the product architecture to adapt current automobile designs to simplified mechanical requirements; and
(4) modify the subsystem interfaces to accommodate a different energy input in a plug-and-play configuration.

Changes to the fuel cell that result from changing its energy source will change the interface requirements and the product architecture. Emerging sensor technology may enhance the PEM fuel cell's operations, but there are competing fuel cell configurations such as the solid oxide fuel cell that do not require a reformer and thus are not sensitive to CO. The end performance of the automobile, however, is directly related to the fuel cell since it will impact the way that the automobile will accelerate, particularly from a stopped position.

Thus companies betting on fully electric or hybrid vehicles are all making choices along a complex spectrum about which technology point solutions, subsystem interfaces, and product architectures will offer the most compelling solution in the market place. Moreover, these solutions are evolving at multiple points in the supply chain or network and so no single actor possesses the breadth or depth of knowledge necessary to adequately assess all alternatives. It will not be a fuel cell manufacturer or a sensor manufacturer whose decisions determine the configuration that ultimately succeeds. Rather success will be determined by decisions made – either implicitly or explicitly – by the network of firms contributing knowledge and components, subsystems and systems into a fuel cell or hybrid vehicle solution. This paper argues that the collective decisions should be coordinated in such a way that outcomes are explicitly determined through *a priori* information and planning.

4. Knowledge requirements to support distributed innovation

Because co-innovation is a creative endeavor, the knowledge that is shared within and across the network can be described as occurring along a continuum – nebulous, ill-defined information that may or may not have value on the one end; to specific problem-based information that answers a known question on the other end. In between lies data that *might* become information, and ultimately, knowledge, if the correct person learns it at the appropriate time.

Innovation occurs when previously known information can be applied in a unique way to create a solution. The solution must have value, must be cost effective, and must be competitive with other market offerings. This requires complex exchanges across multiple channels. Unfortunately, traditional information systems that support collaborative networks are patterned on known channels of communication and well-defined handoffs of information between stages of development.

From a knowledge management perspective, a supplier network must have a framework in which diverse information can be gathered and organized to replicate across the supply chain or network the knowledge sharing that Nonaka (1994) once associated with the successful vertically integrated corporation. Nelson and Winter (1982) argue that tacit knowledge in an organization is different than tacit knowledge of the individuals within the organization, and their argument can be extended to the network environment. One key to effectiveness of a network is the ability to use tacit knowledge to understand and expand explicit knowledge, and to transfer this newly created knowledge to others who can understand it and have the strategic experience to make use of it. The use of tacit knowledge combined with the explicit knowledge at the firm level must be captured by the network to achieve efficient and effective innovation (Petrick and Maitland, 2005).

5. Crafting policies and procedures to achieve situational awareness

To achieve situational awareness at both firm and network levels will require scholars and practitioners of R&D management to firmly articulate policies and procedures for the creation and sharing of tacit and explicit knowledge, with a focus to the structural, relational and cognitive aspects of social capital (Nahapiet and Ghoshal, 1998). Social capital creates a framework to improve the efficiency of actions, thus reducing the cost of transactions while also considering learning (Ring, 1996) and coordination (Gulati and Singh, 1998). Traditional resource based views of the firm's core competencies and dynamic capabilities need to be expanded to a network context, with an emphasis on knowledge creation and sharing leading to firm-based situational awareness and translating into network-based situational awareness.

King's effective knowledge organization (King, 2006) can be extended to the notion of a network. Here, the network must share an architecture that links core knowledge management with intellectual property management and organizational learning, and which also supports the co-development of new knowledge by a distributed set of experts enabled by information technology modules that created a shared framework for creation tasks such as brainstorming, for example. Thus an information technology infrastructure is a necessary component to achieve situational awareness.

Similarly, firm policies must begin to accommodate the realities of network needs and the practices of networked innovation. As market uncertainty increases, as is the case in networked innovation, the need for one firm to reach out to other organizations to provide valuable and unique information rises. Tier 2 and 3 suppliers operating in different scientific and technical domains possess access to different technical experts. Moreover, when these suppliers are located in different geographical regions, the pool of experts expands as well. This suggests a two-fold criteria to choose suppliers: (1) technical diversity and (2) geographic diversity. These criteria ultimately may be as important or more important than the current focus on choosing suppliers by cost. For example, in the short term it may be the "China price" that encourages off shoring to China (Engardio, Roberts and Bremner, 2004). However, in the long term it may be access to the more than 350,000 new technical and engineering experts that China trains annually that will yield significant innovation value to the network.

Distributed expertise and knowledge gathering will change the relative power structures in the supply chain (Petrick, 2006) as firms that provide unique technical capabilities and unique access to experts will add more value to networks than those that do not. The companies that can adapt their product development, manufacturing, collaboration/partnering and supply chain acquisition policies to reflect the way that the network's overall competitive advantage is derived through the combined resources of the extended enterprise will be the ones to achieve higher levels of success.

Figure 2 emphasizes the networked nature of the development of the product portfolio. Here, inputs must come from knowledge of external factors such as the environment and the market into which the product or portfolio will be introduced. Typically this knowledge will come from the OEM. However, the OEM and its suppliers must combine their own internal resources with the collective resources of the network to effectively engage in the basic, applied and development research needed to support innovation. The capabilities of the network include the external and internal resources. The capabilities of the firm, on the other hand (reflected on the left lower portion of Figure 2) indicate that the each firm must develop its own internal capabilities *and* that its strategies for outsourcing and partnering must balance internal capabilities with the capabilities of others.

To date, outsourcing and partnering strategies have developed as the result of historical relationships between firms, often built on the triumvirate of cost-schedule-quality metrics. Such metrics do not capture innovative capabilities and will need to be reconsidered as firms seek to align themselves with one network or another. Supply chain management and sourcing decisions must change from a procurement focus to embrace the broader distributed competencies focus (Petrick, 2006).

Kogut (2000) asserts that the network, though a collection of firms, does not consist of an authority relationship that can enforce organizational structure on its members. Emerging supplier management practices that emphasize both coordination and collaboration must,

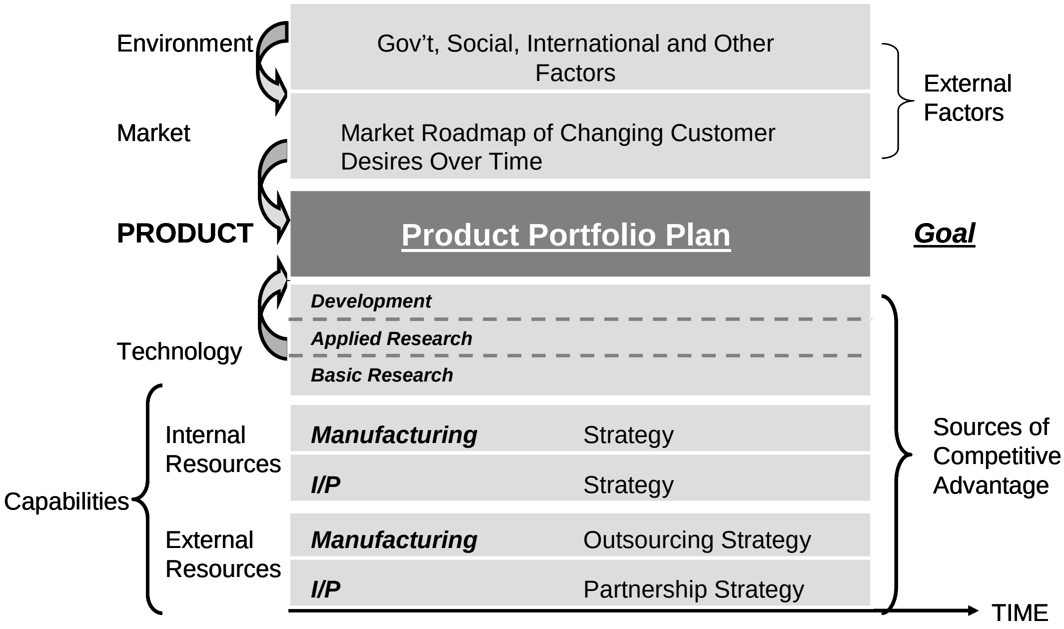


Figure 2: Networked Competitive Advantage Comes from the Collective Resources of Individual Firms and their Ability to Combine Knowledge of Multiple Fronts into Collective Action

by design, reduce the emphasis on enforcement and instead increase the desire of individual firms to participate in activities that support collective growth.

The adage 'with knowledge comes power' will dominate network effectiveness in the years to come. For individual firms to sort through data to identify the relevant pieces, requires that the firms understand the way that their components contribute to the overall competitive advantage of the product. For distributed innovation to truly yield competitive advantage, network policies must evolve in such a way that information sharing is supported and incentivized. Furthermore, they must evolve in a way that supports organizational learning (Knight, 2002). Knowledge building and sharing practices that create situational awareness for the network and its participants represent a critical capability that firms must be ready and willing to develop and deploy.

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