Pergamon

European Management Journal Vol. 17, No. 4, pp. 335–347, 1999

Printed in Great Britain
PII: S0263-2373(99)00014-6
0263-2373/99 $20.00 + 0.00

Knowledge Management Across Multi-tier Enterprises: The Promise of Intelligent Software in the Auto Industry

JACK G. OLIN, *University of North Carolina at Chapel Hill*
NOEL P. GREIS, *University of North Carolina at Chapel Hill*
JOHN D. KASARDA, *University of North Carolina at Chapel Hill*

The automotive industry is at a critical juncture in its evolution. Vehicle manufacturers are merging horizontally into large portfolio-oriented companies focused on assembly and marketing while reducing their in-house development and manufacturing depth in favor of a multi-tier supplier base. This realignment has increased organizational flexibility and global technology access, but concerns have been raised about the industry's ability to manage complex product programs across multi-tier interfaces — and about knowledge leaks to competitors. In this paper we argue that these virtually integrated enterprises are not well served by hierarchical planning tools and dedicated communications networks. Instead, distributed intelligence in an open-architecture and secure enterprise network provides the connectivity needed for successful product development and delivery. Emerging software tools such as intelligent agents or applets, common in Internet applications such as assisted personal computing, are well-suited for coordinating complex product management processes in multi-tier enterprises. As these new information technologies advance, competitive success will depend on the intertwined evolution of these embedded software tools and the new business processes that they are creating.

Introduction

Industries engaged in the design and manufacture of complex products such as automobiles, commercial aircraft and defense systems are engaged in a well-documented restructuring of their supplier relationships. Driven by a confounding of environmental and competitive factors, companies within these industries are merging into marketing giants, as demonstrated by the recent merger of Mercedes Benz and Chrysler. At the same time, these companies are restructuring their supplier relations around a minimum number of full-service development and logistics partners (Fleisher, 1996; Proctor, 1997; Stundza, 1997). Previously integrated supplier divisions are being grouped into subsidiary enterprises under the umbrella of the parent company or spun off entirely. General Motor's decision to spin off its component group Delphi Automotive Systems is a recent example.

These trends are consistent with the concept of the virtual enterprise — a strategic alignment of companies that join their core competencies in response to market opportunities. Virtual enterprises have demonstrated improved responsiveness and efficiency in the manufacture of many products. The personal computer industry is an example of how successful virtual enterprising can be for a product that has reached the necessary maturity for modularization and standard interface parts. Companies like Dell ensured their success by building a virtually connected supplier network in which suppliers compete on price and quality in the production of standardized components that can be delivered and assembled into customized products within 24 hours.

The case for virtualization is less obvious in industries such as the automotive industry that are characterized by market-driven product differentiation and complex supply chains. For example, while vehicle structures such as cockpits lend themselves to modularization and related outsourcing (Collins *et al.*, 1997), functional subsystems such as drive-train or integrated ride-and-handling systems are not as likely to be outsourced because of the need for tightly integrated development and engineering, and the risk of technology loss or dependency. For such vehicle-integral functions, the trend is to engage trusted first-tier suppliers as development partners under the strict control of the manufacturer. A case in point is the Mercedes/Bosch collaboration in developing the ESP (Electronic Stability Program) first introduced in the S-Class and now applied across the Mercedes vehicle portfolio.

Such tightly controlled extended development partnerships are a form of virtual enterprising but must be differentiated from the virtual world of, for example, the personal computer industry. One can differentiate levels of 'virtuality' in extended enterprises based on the need for control by the end product manufacturer. In the *virtually distributed* personal computer industry, horizontal layers of independent component suppliers compete on standard interface parts. In the *virtually integrated* automotive or aerospace industries, companies and suppliers collaborate on vehicle systems in tight partnerships. PC-style virtual enterprising relies on electronic data interchange (EDI) to manage the global logistics needed for fast, postponement-based delivery of parts and components. Extended enterprising for the development of complex, highly integrated vehicle systems and modules, however, requires much more. Here, the product development processes of the partners must be connected and integrated — across geographic, organizational and cultural borders as well as time-zones — to produce the 'best' vehicle solution.

This paper addresses the need for a coherent information strategy that leverages the 'universal' information environment of Intranets, Extranets and the Internet to enable human and software-based connectivity across the inherently complex organizational and geographic boundaries typical of multi-tier enterprises. We focus, in particular, on the convergence of current industry restructuring and advances in 'intelligent' information tools. Enterprises need to understand how these new technologies are changing established value chains and business processes. In many companies, there is still a tendency to develop information technologies that support existing business processes. Instead, these processes and technologies must evolve together — especially in global enterprises producing complex market-sensitive goods.

The paper begins with a review of the trend toward virtual integration in the automotive industry, followed by a closer look at strategic factors that determine manufacturers' (un)willingness to embrace this new organizational alignment. Issues related to confidentiality and program management in virtual enterprising are addressed. We then focus on the critical and competitive need to move from hierarchical management systems in dedicated networks to distributed intelligence in an open information environment. We describe information technology-based approaches for program management featuring technology enablers such as content firewalls for information filtering and intelligent agent software for managing the increasingly complex communications process associated with far-flung assembly operations and product development processes straddling multi-tier supplier partnerships. Applications in product development and logistics that can leapfrog companies ahead of their competitors are described.

The Challenge of Increasing Complexity

Complex industries differ from their counterparts not only in the complexity and sophistication of their products, but also in the scope of the relationships that must be managed to produce just a single product such as a car, a truck or an airplane. The design and production of complex products has only become more intractable in today's fast-paced competitive environment where technology and customer fancy can transform themselves almost overnight. This is especially true of the automotive industry that has been buffeted by recent changes in the marketplace. In the 1970s and 1980s, the convergence of three external events — the oil crisis, the emergence of a competitive Japanese auto industry, and an intense awareness of the fragility of our physical environment — rocked the automotive industry in both the United States and Europe. These events stimulated a new focus on customer responsiveness, reliability and quality that has led to enhanced relationships and increasingly tighter lines of communication with suppliers.

Beyond the challenge of establishing a responsive and efficient supplier network, the industry has been struggling to integrate new participants into the supplier constellation. Advances in information technology have led to breakthroughs in IT-enabled vehicle technology ranging from intelligent transportation systems to vehicle safety, security and information features. The impacts of these technological advances, while equally dramatic, are even more subversive in that they require automotive companies to search beyond the traditional stable of suppliers for partners capable of providing specialized technology and design capability. These further extended enterprises broaden the definition of suppliers/partners and add significant complexity to the vehicle program management process. Partners now include expert firms in areas ranging from telecommunications to information technology who do not have existing supplier relationships with the industry and who may not understand their customers' internal systems and culture (White and Bank, 1998).

The recent trend toward virtual integration has added another layer of complexity to the problem of vehicle program management. In virtual integration, first-tier suppliers and their development partners join with the vehicle manufacturers and second-tier suppliers in an extended enterprise in which business processes, for example product development processes, span organizational boundaries. Within the virtually integrated enterprise, for example, product development activities are managed as a set of integrated processes that span the organizational boundaries of the partners. The shift from a vertically integrated production architecture in which supplier divisions and vehicle divisions are managed hierarchically by the vehicle manufacturer to a virtually integrated development partnership is represented schematically in Figure 1. The specialty houses, including non-traditional supplier categories such as telecommunications and information technology, participate as integral partners to the joint development process.

The automotive industry is learning from the shift towards virtual integration in other industries, yet, as we will see in the next section, is tailoring its efforts to its unique objectives and complexities. The notion of modular consortia is one expression of virtual integration. Modular consortia apply virtual principles to the production and assembly processes. The relationship among consortia members is governed by a long-term — yet reconfigurable — contractual relationship between the manufacturer and a small number of first-tier suppliers. Members of the consortia or extended enterprise operate as equal partners and co-investors in a dependent, yet efficient, relationship. Typically, one of the partners acts as the *primus inter pares* with overall leadership in interface management responsibilities.

In a modular consortium, the supplier/partner is responsible for assembling a module close to the manufacturer's location utilizing just-in-time (JIT) and sequence-in-line-supply (SILS) principles. As noted by Collins *et al.* (1997), these suppliers assume responsibility for modular assembly, on-line final module assembly into the vehicle, and management of the module supply chain. The automotive manufacturer supplies the physical facility and assembly line, and assumes responsibility for plant coordi-

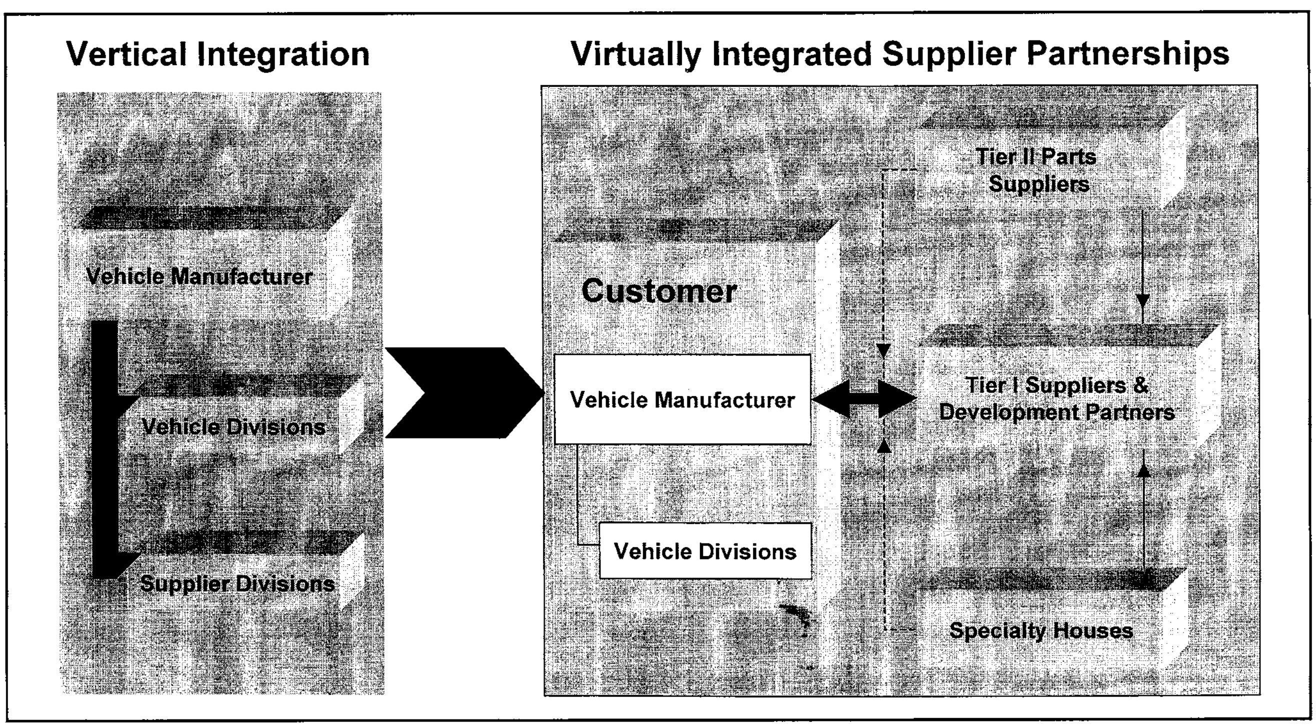


Figure 1 From Vertical to the Virtual in the Auto Industry

nation and final testing. Such a model describes Volkswagen's new truck and bus experiment in Resende, Brazil where seven module suppliers currently produce 30,000 trucks and bus chassis each year. Some manufacturers even pursue consortia-based ownership of their assembly facilities.

Beyond modular consortia, enterprise-based virtual supplier partnerships are also providing agility in the product development and delivery process. A live experiment in 'going virtual' is the Mercedes/Hayek Micro Car Company (MCC) joint venture in which a small core team leverages nearly all development activities through a network of virtually integrated partners. MCC management defines the strategic direction and design envelope for the vehicle; all else is sourced through MCC-led supplier consortia comprised of a limited number of first-tier suppliers who are 'owners' of major vehicle subsystems and modules. This arrangement is made possible by modularized vehicle design and the corresponding task distribution among suppliers. The MCC Smart Car went into production in late 1998 and the success of this experiment in virtualization is currently being assessed.

From Vertical to Horizontal: A Closer Look At Industry Realignment

Between traditional, vertically integrated manufacturers who limit supplier involvement to outsourcing and full 'virtuality' as demonstrated by MCC, there is currently a continuous spectrum of supplier relations. The general trend, as outlined in the introduction, is toward partnering with trusted first-tier suppliers who, in turn, are supported by lower tier parts manufacturers in a multi-tier arrangement. In the automotive industry this trend is being accompanied by a major industry restructuring characterized by horizontal mergers of key manufacturers and the creation of integrated supplier networks. Vehicle manufacturers are merging into global players capable of covering market demands across the globe. The DaimlerChrysler merger is a case in point. The new auto giant covers the spectrum from Americans' nostalgia for one of Detroit's unique luxury offerings to Europeans' expectation for ride and handling on the German Autobahn. At the same time, these global mergers are focusing as never before on their core competencies as marketing and portfolio management entities.

The horizontal merging of assemblers into global enterprises is accompanied by a simultaneous de-verticalization of their supply base as shown in Figure 2. As formerly captive suppliers are spun off by vehicle manufacturers, the suppliers themselves are merging into systems-capable, and often full-service, first-tier partners to the assemblers. As such supplier mergers take place, a multi-tier structure emerges in which large, integrated suppliers rely on second and third-tier component suppliers for parts and access to component-specific technology such as innovative materials or manufacturing processes.

Mergers and extended partnerships introduce new roles for automotive companies and systems-capable suppliers alike. Previously, suppliers were required to produce a component or assembly to given specifications which was then assembled by the manufac-

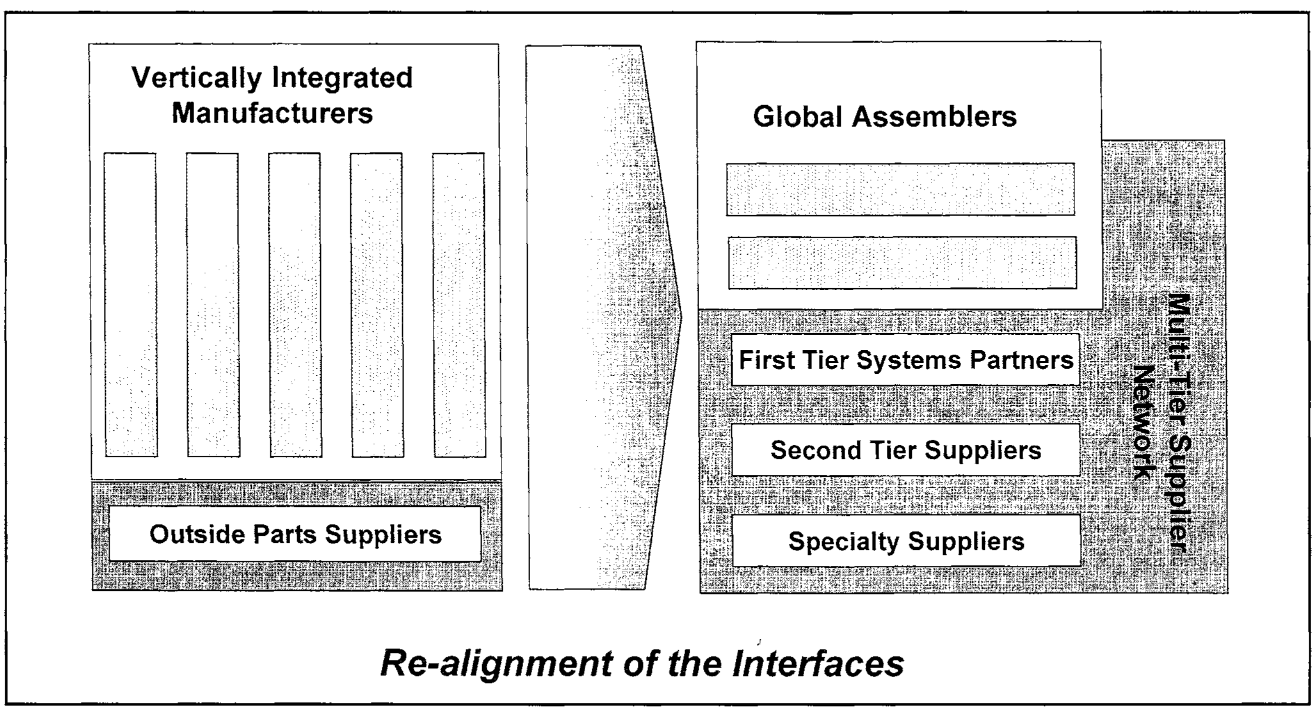


Figure 2 From Vertical Integration to Horizontal Multi-tier Enterprising

turer into vehicle systems. Systems-capable, first-tier suppliers must now be able to develop and design subsystems to assemblers' specifications and work with the assembler on subsystem integration into the final product. A recent automotive example is the collaboration between Mercedes Benz and its supplier Bosch in the development of the Electronic Stability Program, or ESP, mentioned earlier.

Other examples are Delphi Automotive's E-Steer, an advanced electric power steering system, and Galileo, an advanced brake-by-wire system, as well as supplier-developed integrated vehicle modules such as pre-assembled cockpits. Full-service suppliers bring their core competencies to the task of designing to specifications and managing all aspects of the program. These aspects range from design, progress reviews, validation, manufacturing, quality assurance, sourcing and distribution logistics, to modular pre-assembly (as appropriate) and, in some cases, vehicle installation of their product at their customer's assembly line. Figure 3 illustrates the tight collaboration of systems-capable and/or full-service suppliers working in tandem with vehicle manufacturers.

The benefits of both horizontal merging and the multi-tier structure in the supplier industry are clear and have been documented. The most significant to date have been the ability to leverage the best design and logistics players in the industry through extended partnerships. Globally networked manufacturers can spread their risk across regional markets and can define product portfolios based on common platforms. These platforms can be customized to unique regional expectations. Virtual enterprising with a multi-tier supplier base also gives manufacturers added flexibility and speed-to-market through platform-specific partnerships assembled around needed core competencies. Such partnerships are reconfigurable as needed and give manufacturers global technology access difficult to achieve through captive suppliers.

The Challenges of Virtualization in Complex Industries

There are, however, challenges and risks associated with virtual enterprising. Not all manufacturers have fully embraced the new paradigm of virtual partnering with systems-capable and/or full-service suppliers as first-tier partners. While there are pragmatic reasons for this reluctance, such as slow attrition of in-house personnel and concerns about the effort and cost of 'teaching' outside partners, two concerns appear paramount:

- The need for highly integrated product development processes to assure functional and structural integrity in complex products, and
- The risk of knowledge loss to competitors and the related technology/know-how dependency on suppliers.

These two concerns are interrelated. The very solution to the first concern confounds the second. Competitive real-time management of complex product

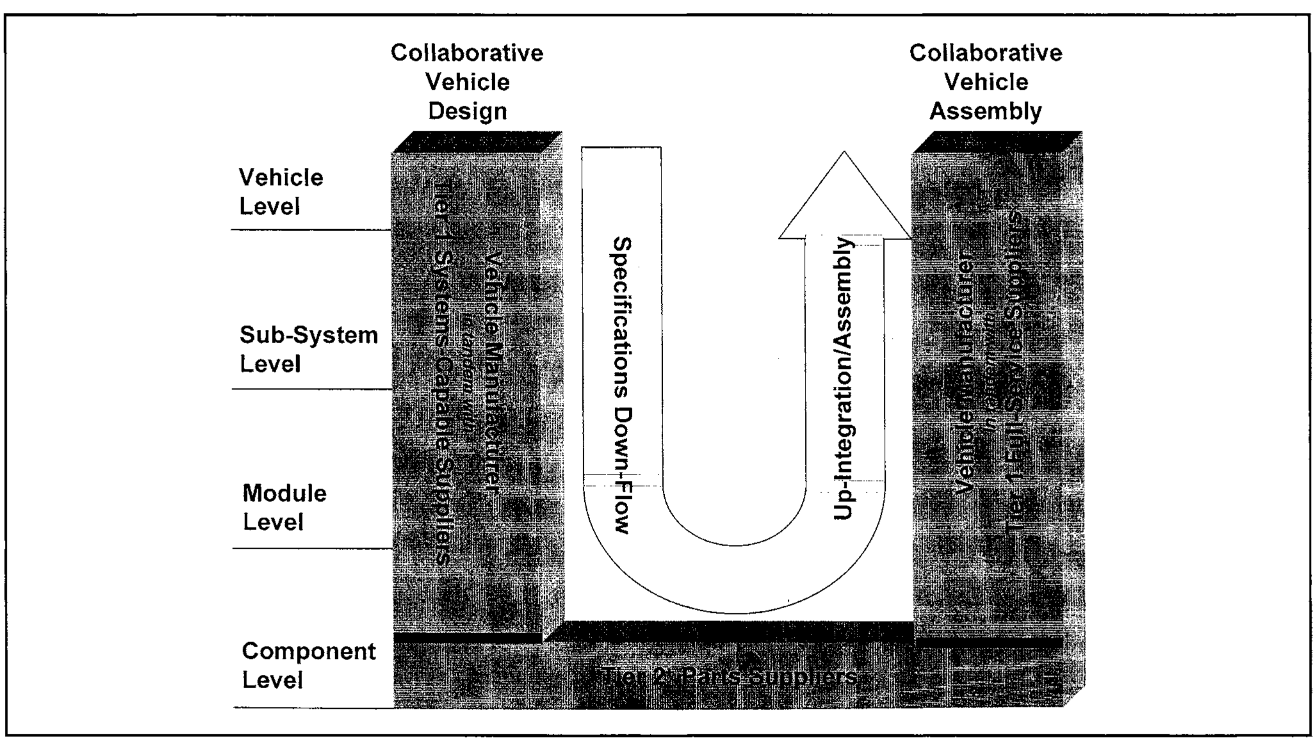


Figure 3 A Multi-tier Automotive Supplier Network (Working in Tandem with Vehicle Manufacturers)

programs across organizational boundaries requires an information environment and IT tools capable of linking suppliers worldwide in a real-time information exchange. Yet these same technologies represent potential channels for knowledge loss to competitors. While firewalls and encrypting technology can address this concern at the tactical level, enterprises are still faced with the need for strategic risk management — balancing the need to share information among partners against the risk of preemptive know-how loss to the competition and dependence on suppliers.

Some observers claim that nothing less than the future control of the automotive industry is at stake. During the era of vertically integrated manufacturers and component outsourcing, the competitive front lines were well-defined. Manufacturers had a rather broad definition of their own core competencies and maintained the associated technological know-how within the company's organizational walls. Outsourcing was typically limited to commodity items that were shared broadly across the industry. Subsystems and modular assemblies requiring intensive cooperation between manufacturers and their suppliers in engineering and assembly logistics were managed inside the manufacturer's firewalls. In this way, the technology value-chain was visible and controlled.

The new era of virtual enterprising — with development partnerships and consortia that involve many outside or non-allied, systems-capable, full-service suppliers — has changed all that. Joint R&D and systems engineering in extended partnerships can only produce optimal results if organizational boundaries become porous enough to allow the sharing of essential technical knowledge on a need-to-know basis. For example, vehicle-level specifications need to flow from manufacturers to first-tier partners as the basis for subsystem and modular development. And technology and know-how need to flow from suppliers to manufacturers, as well as from parts suppliers to first-tier suppliers, if development partnerships are to result in the 'best' design solutions for manufacturers.

For vehicle manufacturers, then, the perceived risk of core knowledge leakage to competitors, along with technology dependency on suppliers, is one of the most severe obstacles to the embracing of virtual enterprising for development with all its implied benefits in flexibility, cost, and innovation. Since complex products such as aircraft and automobiles compete on innovation in styling, features, and underlying technology, know-how in these domains represents a key differentiator in the marketplace (Kurylko, 1997). The loss of this know-how to competitors could place a company at significant risk. This leads to a dilemma inherent in development partnerships — how to reconcile manufacturers' need for access to the best technology with the need for protecting in-house core competencies.

Supplier groups allied with major manufacturers also find themselves in a new and troublesome situation. These allied suppliers are expected to compete outside their parent company to establish their market-based competitiveness, yet must protect their parent's proprietary technology and know-how. Typically, these suppliers have evolved from in-house parts manufacturing operations to status as independent systems-capable, full-service suppliers under the corporate umbrella of their respective parent corporations. These suppliers are asked not only to support the parent corporation, but also to compete in the non-allied market. In short, the parent corporation expects these allied suppliers to compete against the worldwide supplier base without the traditional advantage of getting the parent corporation's business (more or less) automatically.

Delphi Automotive Systems, prior to being spun off by GM, exemplified the challenge faced by allied suppliers who need to compete 'outside,' yet have strong cultural and systemic ties to the parent corporation. Delphi has grown from some 14 parts manufacturing operations into a global operator whose customer base includes almost all European auto makers, as well as North American and Asian manufacturers. With the recent integration of Delco Electronics, Delphi Automotive Systems now has the potential of becoming a truly systems-capable partner to the global auto industry (Blumenstein, 1998). Yet even after independence, suppliers like Delphi with strong bonds to their original parent must redefine their identity as independent suppliers and build well-defined safeguards into their partnership interfaces.

Suppliers have a vested interest in safeguarding knowledge that is shared by their customers during the product development partnership. Partnering relationships are built around the trust that proprietary information will not be disclosed to competitors. Strong supplier relationships and cultural bonds take a long time to build but can be breached with a single transgression. These 'information loops' in allied supplier relations could give rise to confidentiality conflicts if not managed carefully. In the past, some supplier subsidiaries have succeeded in building a non-allied customer base by demonstrating that they can indeed protect confidential information. But full acceptance as systems development partners will require more formal definitions of intellectual property, and policies for managing knowledge. Otherwise, the full benefits of development partnerships in virtually integrated enterprises may not be realized.

There are past examples of very successful ventures in virtual enterprising in the auto industry — even at a time when 'virtual' was not yet a catch phrase. In the early 1990s, Chrysler Corporation slashed costs while offering stylish new models by focusing on its core competencies in vehicle-level design and assembly, leaving all else to suppliers. However, Chrysler's strategy might be described as risky since it could lead to technology dependency (Fine, 1998, pp. 1159–60). In this light, the recent Chrysler/Mercedes merger may well be viewed as a superb strategy, since the new enterprise covers the spectrum of capabilities from heavily leveraged product development and delivery to cutting-edge vehicle technology.

Coping with Complexity: Universal Information Environments

Many companies are adopting enterprise resource planning (ERP) systems to control business processes across the enterprise; however, these systems do not provide the flexibility and responsiveness that is essential in dynamic markets. Traditional top–down approaches to information management are increasingly unable to coordinate complex business and development processes across multi-tier boundaries while allowing the sharing of essential know-how between partners. Without the timely emergence of an information environment based on a universal tool set, the multiplicity of these complex interfaces will not be manageable on a global basis. New Internet technology-based information infrastructures with universal, open standards enable industry to cope with the complexity inherent in such multi-supplier partnerships and consortia. Filtered interfaces to the Internet, other industry Extranets, and enterprise Intranets provide both access and control.

The need for a new information environment is especially critical as the industry moves beyond modular consortia to development partnerships focused on systems-level optimization and modular design. Product development entails a series of phased activities separated by management progress reviews. The phased activities range from advanced development and concept definition to engineering, prototyping, and manufacturing (Khurana and Rosenthal, 1997). In each phase, information must be shared across all members of the joint development team. Shared information includes high-level vehicle requirements, systems-level specifications, component-level specifications, concept alternatives, technology alternatives, product and process engineering solutions, detailed drawings, quality systems, manufacturing and assembly systems, and supply and assembly logistics. While only some of this information will represent a truly preemptive competitive advantage, all of it represents know-how that should not flow into projects with competing manufacturers.

This suggests that 'firewalls' need to be established in the outer perimeter of the partnership to protect know-how leaks to competitors. The firewall concept is borrowed from information technology, where firewall software selectively channels information, especially confidential information, through controlled interfaces between information systems. Firewalls can be an effective mechanism for enforcing a security policy between an organization's internal systems and the external world. Security policies implemented through firewalls determine which inside services may be accessed from the outside, and even who internally has access to that information. In the case of the extended development partnership, the perimeter defense is enlarged to encompass access on a need-to-know basis for all partners. Firewalls simplify security at the perimeter by consolidating network access to a central point of entry or refusal.

How can suppliers manage multiple firewalls within their organizational walls? As Figure 4 suggests, information should flow ideally from the supplier's core knowledge base to the various development partnership teams only. Some information tunneling through perimeter firewalls may be unavoidable, or even desirable, but can be kept to an acceptable minimum with the right management systems and culture in place. In reality, knowledge transfer from the

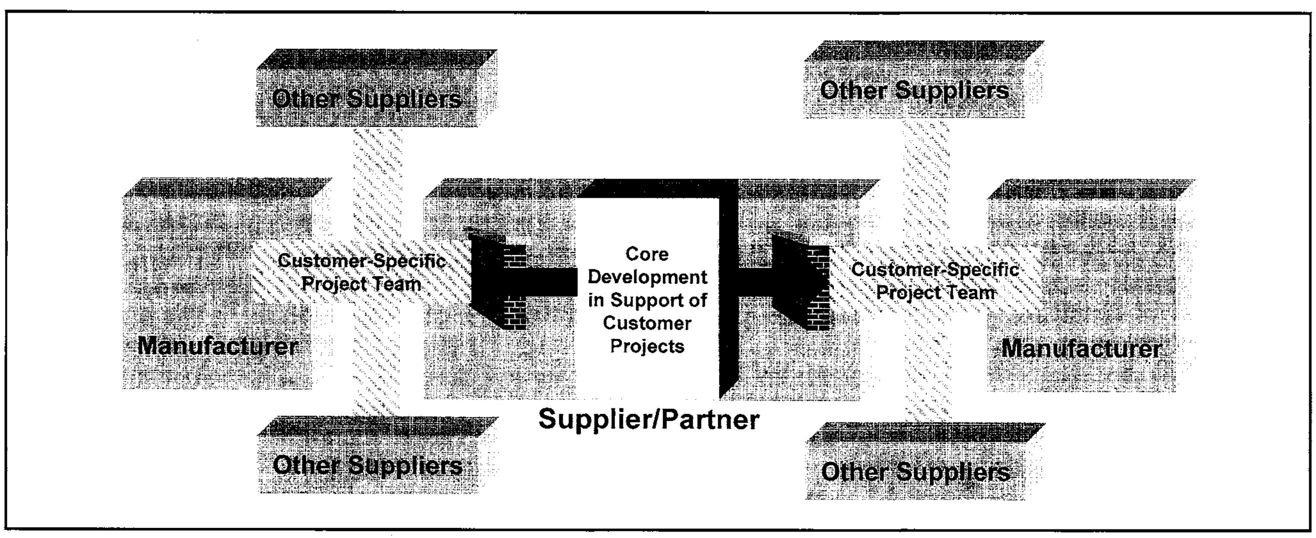


Figure 4 Knowledge Transfer in Joint Development Projects (Customer Support without Know-how Crossflow)

manufacturer to the supplier's core team will happen simply because of experience gained by the supplier's experts. As long as this is managed responsibly with respect for customers' proprietary information, such professional growth in the supplier's experts will bring long-term benefits to the whole industry in the form of better products and systems.

Intranets and Extranets as Global Competitive Tools

Because of its user friendly 'anywhere-anytime' access, web-enabled information has already emerged as a potent competitive weapon by enabling concurrent product development on a global scale. It is not surprising, then, that some of the most successful recent examples of internet-aided product design are found in complex industries such as defense systems, commercial aircraft and automobiles that involve suppliers on multiple continents. Probably the best known recent example of complex product design within a virtual environment is the Boeing 777. While this effort was not yet fully Internet-compatible, it represented a major step towards an information-based development partnership. Boeing communicated with its five engineering partners in Japan using hard-wired dedicated underwater cables. With the subsequent introduction of browser technology in an Internet, Intranet or Extranet environment operating on a common transmission control protocol/internet protocol (TCP/IP), access among suppliers regardless of platform or network configuration becomes possible.

In the automotive industry, the 'Big Three'-initiated Automotive Network Exchange (ANX) governed by the Automotive Industry Action Group (AIAG) is the first comprehensive automotive network based on universal Internet protocols and tools. Initially, ANX will link manufacturers and suppliers in the exchange of electronic forms for business transactions, saving an estimated $1 billion per year across the industry. However, the network has the potential to support virtually-integrated processes from vehicle development to delivery, and can be expected to lead to significant reductions in development cycle-time and cost (Pappalardo, 1997). When ANX goes on-line in 1999, it will link General Motors, Chrysler and Ford Motor Company with more than 10,000 suppliers worldwide (Stevens, 1997). The Association of German Automobile Manufacturers (Verein Deutscher Automobilhersteller) is launching a similar initiative to develop a European Automotive Extranet with initial support from Audi, BMW, Bosch, Ford, Opel, Volkswagen, and Volvo.

As we noted earlier, however, access can be a double-edged sword. While it enables global design teams to operate in a virtual design environment and can provide global supplier access, it also poses security concerns about how to protect proprietary information. Fortunately, in addition to providing the connectivity for virtual integration among development partners, internet technologies and their enterprise derivatives also provide the firewall technology and information flow control mechanisms needed to protect knowledge and build customer confidence. The Automotive Network Exchange (ANX) initiative outlined above is an example of an Extranet with built-in firewalls and safeguards. While this effort faces major challenges in achieving all the stated objectives, it will eventually put the implementation of information security in automotive enterprises into the realm of software control. When that point is reached, a major hurdle toward 'going virtual' in supplier involvement in R&D and systems integration will have been removed.

With ANX, the auto industry is demonstrating that effective virtual integration of systems-capable, full-service automotive partners in an electronic environment will be a powerful enabler for getting new products to market fast. As Extranet-based automotive partnerships emerge across the globe, a key competitive differentiator for suppliers will be their ability to participate fully in such Extranets by using universal Internet protocols, tools, and formats for all their communications. The first step for suppliers and manufacturers to date has been to web-enable all internal communications in an Intranet environment, then 'connect' to Extranets and the internet through properly managed firewalls. By providing real-time, non-redundant, anytime-anywhere information exchange among partners, companies such as Boeing have slashed development time and reduced costs while, at the same time, improving product quality. Automotive companies who fail to do so now run the risk of missing a window of opportunity to be among the leaders in networked partnerships.

Intelligent Network Applications — The Next Competitive Advance

The next wave of competitive advance within the framework of open architecture networks will be distributed intelligence and decision-making capability in the form of intelligent agent software. In the auto industry today, information is still managed largely by hierarchical planning systems using dedicated networks. The challenge will be to identify the key applications for distributed intelligence across the enterprise — those 'killer' applications that will benefit greatly from an open, hyperarchical information environment (Evans and Wurster, 1997). To date, these applications have been limited to cost avoidance through on-line management of administrative processes such as personnel administration or travel management. In the future, these applications will span the total extended enterprise business environment.

Intelligent agents are special types of software objects, made feasible for real-world applications by object-based languages such as C + + and Java. IBM's initiative to commercialize 'aglets,' an expression derived from intelligent agent applets, is a recent example. Intelligent agents are capable of communicating with each other and reasoning about information contained in messages that pass among them (Rzevski, 1999). These software objects are trained to make decisions under conditions of uncertainty and to act upon incomplete information without human intervention. The behavior of a distributed system populated by agents differs significantly from that of a traditional rules-based, hierarchically-structured information system. In contrast, distributed systems 'distribute' the decision-making throughout the network close to the action so that decisions are made based on local knowledge. These systems are deemed intelligent because they can sustain a desired behavior in the presence of unpredictable events. While distributed intelligent systems sacrifice predictability, they gain in agility, responsiveness and the possibility of self-organization.

Distributed systems are deemed intelligent because they can sustain a desired behavior in the presence of unpredictable events

Enterprise Intranets, and by extension industry Extranets, populated by intelligent agents enable virtual integration in a way not feasible before the emergence of the Internet. Administrative tasks such as component sourcing and purchasing can be performed on-line replacing previously cumbersome paper-based activities. Teams of geographically dispersed product designers communicating over the Internet can share ideas in virtual design studios, while intelligent logistics systems can route and re-route shipments based on local conditions. In fact, managing concurrent development processes with real-time synchronization across a well-designed 'capability chain' — be it within an enterprise or across enterprise boundaries — may well be among the most important application of Intranet- and Extranet-embedded intelligent software.

The technical implementation of an Intranet or Extranet may require significant effort on the part of the network administration experts, but the technology is available, favorable business cases exist, and the service provider infrastructure is in place. As in the case of the automotive ANX, service providers will need to be certified to assure the reliability needed in a business or industrial environment, but this too can be accomplished and has been successfully demonstrated. The challenge ahead, then, is the strategic convergence of innovative, network-enabled business processes with emerging technology such as intelligent agent-based distributed networks. In the next sections, we describe two potential applications of distributed intelligence in complex product management processes.

Virtual Design for Global Product Development

Product development in globally distributed, multi-tier industries like the automotive industry — from concept through production and delivery — requires the synchronization of multi-phase processes across the organizational boundaries. In many cases, communications within extended development teams are managed across time zones and geographic boundaries. In the case of BMW's Z3 roadster program, for example, vehicle-level specifications were developed in Munich. Component level specifications and design involved suppliers with engineering centers and component manufacturing in Europe and North America, assembly logistics centers in the United States, and sub-assembly facilities in Mexico. Modular assembly logistics centers for just-in-time delivery of parts, components, and assemblies, as well as SILS delivery of vehicle modules such as cockpits, are located in South Carolina near the BMW plant.

Today's sequential communications processes, whether over dedicated networks or more traditional modes such as fax or voice mail, often lead to serious breakdowns since not all players have simultaneous access to single-point, non-redundant information. Furthermore, the proliferation and control of documents is a major problem. Multiple versions of documents are created as users download, modify, save, and redistribute documents such as specifications, designs, and requests for qualifications, and proposals. In many cases, collaborators assume that there is a common understanding of requirements, only to find out that local practices put their own spin on the interpretation of such documentation.

Real-time, anywhere-anytime availability of documentation in an Intranet or Extranet environment represents a giant step towards eliminating such uncontrolled information proliferation. Furthermore, intelligent agent software can assist in information tracking, filtering, and notification across the whole network. The management of engineering changes is a salient example. A design change in a component destined for multiple global manufacturing locations can initiate a domino chain of problems across the program. These changes may affect physical or functional interfaces to other components or systems and need to be evaluated holistically by all pertinent experts. Designers at each site, equipped with state-of-the-art CAD tools, virtual reality systems and intranet-based technology would be able to remotely access prototypes and designs at partner locations. Global, simultaneous, on-line re-design reviews can reduce time-to-market significantly and can avoid surprises later. Ultimately, intelligent agents will be able to cooperate on simple design tasks, checking design changes against customer specifications and changes at other locations.

Intelligent Logistics

Logistics is no longer simply a manufacturing support function involving the transport of materials from point to point along the supply chain. Logistics is quickly becoming the critical coordinating intelligence that makes the extended enterprise possible — spanning product program management from the generation and distribution of knowledge in research and development to manufacturing, assembly, delivery and service. Intranet- and Extranet-based intelligent software can assist logistics in its new role in a way that dedicated hierarchical networks cannot. For example, as logistics emerges as a key element of competitive strategy, it becomes increasingly necessary to maintain better control over distribution channels. Customers want to know where their products are in the pipeline. But asset visibility is not enough. It is necessary to maintain real-time control of the logistics channels so that customer-initiated changes or problems in the pipeline will not prevent the customer from receiving an order as promised. At the same time, better control does not necessarily mean tighter control. Centralized logistics decisions are often not aware of local conditions that can stop a shipment in mid route. Distributed intelligent networks allow full use of local knowledge to circumvent potential problems.

Consider a world in which shipments navigate their way to the customer through a global transportation network defined by a set of intelligent nodes. In this world, each shipment carries with it an intelligent tag that contains knowledge about its destination, expected time of arrival, carrier, and storage and handling conditions. This tag, a very simple intelligent agent, is capable of updating the shipper about routing changes or delays. The nodes in the transportation network contain their own intelligent agents capable of communicating with the intelligent packages. In the event of a breakdown in transportation, the shipment is able to negotiate new routes, and even rates, depending on local conditions. If there is a bottleneck, the package's agent will re-route itself to avoid the congestion and assure a timely arrival. Such a system offers reduction in both transportation costs and time since it can optimize in real-time.

The capabilities of modular assembly consortia and customer co-located logistics centers will be enhanced by the availability of such a real-time intelligent information environment. Extranet-based intelligent logistics, such as intelligent-agent-tagged parts passing through a network of intelligent transportation nodes, provides a strategy for cost-effective vehicle customization. The arrival of parts and components from all over the world can be synchronized to assure convergence at the point of assembly within a very narrow window of time. In short, the new paradigm of flexible logistics already seen in less complex industries like personal computers will be possible in even the most complex product environment such as aerospace, automotive or earthmoving equipment.

Moving Incrementally

Many large corporations have already established long-term contracts with enterprise software providers to implement hierarchical enterprise management systems that are complementary to existing systems such as materials resource planning (MRP) systems. As a result, the introduction of intelligent software such as intelligent agents must be accomplished as an incremental overlay to these existing systems. Such incremental application of intelligent software needs to be based on: (1) identifying the most critical (costly) communications problems and process breakdowns; (2) targeting those problems that lend themselves to the application of intelligent software agents; and (3) developing a scalable prototype for subsequent adoption.

Since agents are event-triggered, can recognize conditions in their specific knowledge domain, and can collaborate to propose or initiate action, they promise to be most useful in processes characterized by massive communications, coordination and synchronization tasks. For example, in a complex multi-locational, multi-discipline and multi-organizational product development project, agents distributed throughout the network can learn specifications, keep up with and broadcast changes in specifications, check design parameters against specifications, and check designs for structural and/or functional consistency. Agents can also be triggered by schedule changes or delays and notify project management. If agents are trained to observe workload levels, they might also be able to recognize project bottlenecks early on. Intelligent agents can, of course, also be trained to keep secrets, control access by people or other agents to a given knowledge domain and, in case of conflict, alert responsible professionals.

The first step in an incremental approach to product development might be to create an agent network whose functionality is limited to specification and design updates. The agent network might trigger notification of changes to a targeted list of users. At

Table 1 Benefits and Risks of Virtual Integration

Benefits	**Enabling information technology**
Gaining access to outside technology and experience	Real-time, universal access to published information — within firewalls
Leveraging outside systems competence and services	Real-time, on-line development environment (Intranet, Extranets)
Driving competition in innovation, cost, quality, and delivery	Universal visibility of available technology, products, services, pricing
Risks	**Mediating information technology**
Communications breakdown of critical development processes	Intelligent agent software for managing complex interfaces
Loss of sensitive information, knowledge and/or know-how	Firewall technology for filtering information — single point, traceable

the next level, agents can learn 'who needs to be notified about what' from observing the users. In an advanced case, agents may be taught to modify designs automatically. For example, replacing an automotive actuator with a higher horsepower version might be managed by an agent — local or remote — that automatically selects, or at least proposes, a correspondingly higher circuit breaker rating and cable gauge. The agent could be programmed to assess implications for thermal management, and alert the team to possible physical interference caused by the larger device. The same incremental introduction of agents might be used in the logistics arena. Initially, agents may just track assets and update users about asset status in manufacturing, inventory, warehousing, or in transit. At the most advanced level, object-embedded agents might communicate with base station agents to receive instructions for routing or re-routing, quite similar to packet switching in broadband digital data networks.

Conclusion

The shift from global parts purchasing by vertically integrated companies to modular supplier consortia and, finally, to full-fledged virtually integrated partnerships in a universal information environment — albeit with firewalls, filters and agents — presents new challenges. The benefits and risks associated with multi-tier virtual partnering are summarized in Table 1. The benefits — access to outside competencies, full-service support, competitive component cost, and flexibility — must be weighed against the risks. As shown in Table 1, and discussed earlier in this paper, the most threatening risks are breakdowns in the systems engineering processes across multi-tier boundaries and knowledge loss to the competition through suppliers involved in multiple customer programs. Nevertheless, the trend toward extended partnerships in complex industries appears

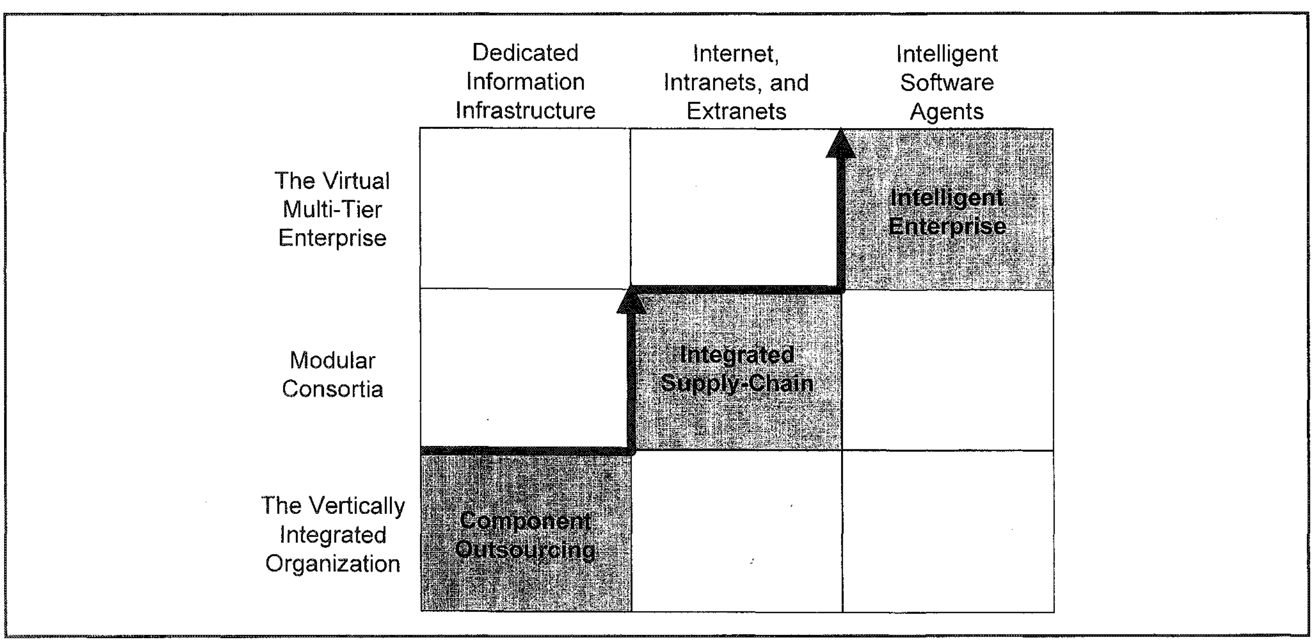


Figure 5 Stepping Up to the 'Intelligent' Enterprise

irreversible. When accompanied by a cultural bias toward respect for intellectual property and a consistent enterprise strategy for leadership — continuing innovation as opposed to protecting yesterday's technology — the threat of damaging knowledge loss is far outweighed by the benefits.

Stepping up to the promise and challenge of what might be best described as the 'intelligent enterprise' is outlined in Figure 5. As we argued in this paper, complex organizations are transitioning from vertical to virtual in distinguishable phases. Similarly, the information landscape is changing in distinct steps from hierarchical, dedicated infrastructures to the Internet and its enterprise derivatives, including embedded intelligent software. These two shifts in enterprise paradigms are occurring in tandem as suggested in Figure 5. Transforming complex organizations from traditional, vertically integrated companies to multi-tier virtually integrated enterprises requires a careful redesign of its communications interfaces and a refocusing of the enterprise culture on the multi-tier environment. Without a consistent and coherent concept for moving quickly, but step-by-step, toward 'virtuality,' organizations run the risk of instability during the transition. Spin-offs like Delphi require up-front strategies for replacing a communications environment based on established self-understood values and practices with an information infrastructure capable of working across the multi-tier, multi-customer enterprise environment.

The emerging real-time universal information environment with intelligent software tools can help to fulfil the promise of the virtually integrated enterprise. The technologies are available and improving continually. Intelligent agents are becoming more intelligent and search engines are becoming more discriminating. Networks are merging into an integrated information environment managed through selective and mature layers of firewalls. The challenge for industries moving steadily toward ever more communications-intensive virtual enterprising is the redefinition of their business and collaborative processes around these emerging technologies. In an open and distributed information environment, key applications consistent with enterprise mission and objectives, can provide sustainable competitive advantage. However difficult it may be to meet these business challenges, companies operating in an open and intelligent information environment with appropriate firewalls and a culture of respect for proprietary know-how will sustain a long-term competitive advantage. Vehicle manufacturers, as well as suppliers, willing to embrace this new paradigm will themselves become catalysts for making it happen.

References

Blumenstein, R. (1998) Auto industry reaches surprising consensus. *Wall Street Journal* 5 January.

Collins, R., Bechler, C. and Pires, S. (1997) Outsourcing in the automotive industry. *European Management Journal* **15**(5), 498–508.

Evans, P. and Wurster, T. (1997) Strategy and the new economics of information. *Harvard Business Review* **75**(5), 71–82.

Fine, C.H. (1998) *Clockspeed*. Perseus Books, New York.

Fleisher, M. (1996) A better idea: working with suppliers. *Automotive Production* **108**(2), 12–14.

Kurylko, D. (1997) BMW will rethink systems suppliers. *Automotive News Europe* 9 September.

Khurana, A. and Rosenthal, S. (1997) Integrating the fuzzy front end of new product development. *Sloan Management Review* **38**, 103–120.

Pappalardo, D. (1997) Automotive extranet sets rules, hires own enforcer. *Network World* **14**(35), 12–14.

Proctor, P. (1997) New strategic focus drives Boeing transformation. *Aviation Week and Space Technology* **146**(18), 20–21.

Rzevski, G. (1999) Logistics for the next millennium: the challenge of artificial intelligence. GLORI internal paper.

Stevens, T. (1997) Internet-aided design. *Industry Week* **246**(12), 51–54.

Stundza, T. (1997) Streamlining supply at Lockheed-Martin. *Purchasing* **123**(3), 60–64.

White, J. and Bank, D. (1998) Computer industry races to conquer the automobile. *Wall Street Journal* 23 February 1998.

JACK G. OLIN, *Kenan Institute of Private Enterprise, Kenan-Flagler Business School, CB# 3440 Kenan Center, University of North Carolina, Chapel Hill, NC 27599-3440, USA.*

Jack Olin has been associated with the automotive industry for more than 30 years, including positions at General Motors, Delphi Automotive Systems and Delphi Packard Electric Systems. During the last five years he has been Director of Engineering for Delphi Packard's European Operations and later Technology Director for Delphi Deutschland. Dr Olin is currently Adjunct Professor at the Kenan-Flagler Business School and Research Fellow at UNC's Kenan Institute of Private Enterprise where he is engaged in research to develop new logistics strategies for the automotive industry.

NOEL P. GREIS, *Center for Logistics and Global Strategy, Kenan Institute of Private Enterprise, Kenan-Flagler Business School, CB# 3440 Kenan Center, University of North Carolina, Chapel Hill, NC 27599-3440, USA.*

Noel Greis is Director of the Center for Logistics and Global Strategy at UNC's Kenan Institute of Private Enterprise. Her research interests are in the area of global logistics and supply chain management, and she advises companies on the application of logistics-based strategies within their organizations. Dr Greis is also working with state, federal and foreign governments around the world to develop new logistical infrastructures for 21st century business needs.

JOHN D. KASARDA, *Kenan Institute of Private Enterprise, Kenan-Flagler Business School, CB# 3440 Kenan Center, University of North Carolina, Chapel Hill, NC 27599-3440, USA.*

John Kasarda is Kenan Professor of Business Administration and the Director of the Kenan Institute of Private Enterprise at the University of North Carolina at Chapel Hill. He has published more than 60 scholarly articles and nine books on organizational development, logistics and competitiveness issues. He is the originator of the Global TransPark concept, a new logistical infrastructure that is being implemented around the world. In addition to receiving many grants and awards, Dr Kasarda has been designated as a Fellow of the American Association for the Advancement of Science and is a Senior Fellow of the Urban Land Institute.

Pergamon

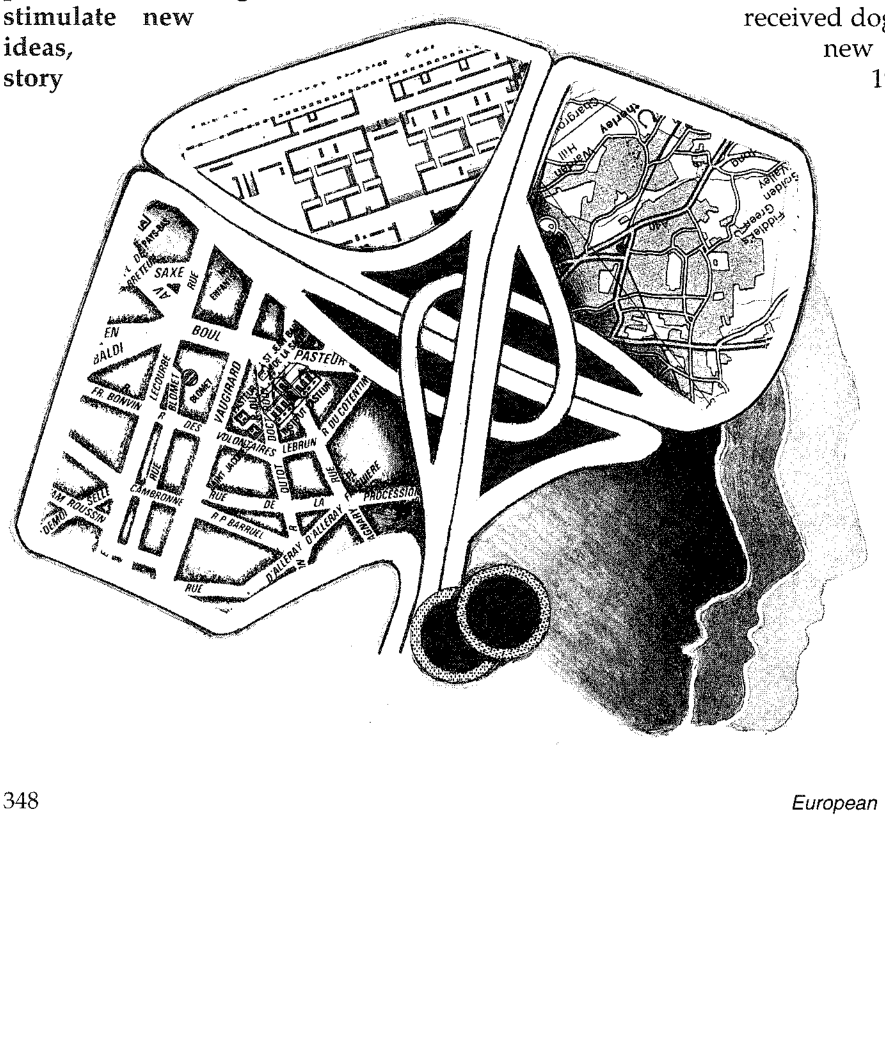
European Management Journal Vol. 17, No. 4, pp. 348–355, 1999

Printed in Great Britain
PII: S0263-2373(99)00015-8
0263-2373/99 $20.00 + 0.00

Towards a New Model of Strategy-making as Serious Play

JOHAN ROOS, *International Institute for Management Development (IMD), Switzerland*
BART VICTOR, *Vanderbilt University, Tennessee*

A new model of strategy-making as play is presented in response to increasing calls for a deeper theory of strategy-making. First an elaboration of the construct of strategic imagination is offered, describing three distinct, but interrelated forms of imagination: descriptive, creative, and challenging. Strategic Imagination is defined as an emergent property of a complex interplay between the three kinds of imagination. Then, extending the work of the planning and design schools, the model describes the complex social dynamic of strategy-making itself. Applying the notion of play from anthropology and cognitive development, the strategy-making process is described as a three-phase play process. The three phases, constructing to stimulate new ideas, story telling to share meaning, and deep engagement to assimilate new directions, are described. Finally some directions for strategy-making practice improvement are offered. © 1999 Elsevier Science Ltd. All rights reserved



The Call for More Imaginative Strategies

During the 90s many calls for more imaginative strategies have been heard from both academia and consultants. For instance, Hamel and Prahalad urged us to '... break out of old paradigms...challenge received dogma...(and) have the courage to ask new questions...' (Hamel and Prahalad, 1996, p. 242). Along the same lines many authors have recently expressed their views of why it is important to 'rethink the future' and how to go about this task (Gibson, 1998). The common thread among these authors is that the essential value of a strategy is its *originality*, and that such originality is desperately needed to navigate the business landscape of tomorrow. Only original strategies will help companies achieve a strategic position *different* from competitors. Without originality a strategy is a commodity and any value would come from implementation.[1] Labeling it strategy innovation, Hamel (1998, p. 7) calls for strategy-makers