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# FROM STATIC SUPPLY CHAINS TO DYNAMIC SUPPLY WEBS: PRINCIPLES FOR RADICAL REDESIGN IN THE AGE OF INFORMATION

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## 1. INTRODUCTION

“A supply chain is the network of organizations that are involved, through upstream and downstream linkages, in different processes and activities that produce value in the form of products and services in the hands of ultimate consumers” (Christopher 1998). Traditionally, management theory has focused on the individual firm as the competitive unit in any industry. However, now it is increasingly recognized that the competitive success of a firm to a very large extent also depends on the competitive position of the firm’s supply chain vis-à-vis other competing supply chains. Competitive advantage of the supply chains is a function of the mode of organizing and coordinating the supply chain, the competence of individual actors in the supply chain, and natural and accidental advantages such as location or access to scarce resources. Organization and design of the supply chain has typically been a product of historical accident, constrained by geographical proximity and the availability of supply chain actors or partners, existing relationships and power structures, limited information processing ability, and relatively limited communication and coordination paths. The advent of modern information and communication technologies (ICT) makes it possible to develop and implement a variety of flexible supply chain design options that can create significant cost and value advantages.

With the exception of limited literature on supply chain reengineering (e.g., Clark and Hammond 1997; Fisher et al. 1997) most of the current supply chain literature takes the existing supply chain as given and attempts to optimize either the material and information flows or inter-partner relationships in the extant supply chain structures. On the other hand, the emergence of new information technologies (e.g., open EDI, the Internet, intranets and extranets) and awareness of new organizational forms such as the virtual organization (Moshowitz 1997, 1999) and dynamic industrial networks (Axelsson and Easton 1992) makes it feasible to completely redesign supply chains to gain cost and value advantages.

*The objective of this paper is to develop principles for IT-enabled supply chain redesign that would reduce the arbitrary constraints imposed by past history, inflexible technologies, and established structures and relationships, thereby providing greater possibilities for designs that can meet the supply chain objectives of reduced cost, reduced cycle-times, and increased responsiveness to customer requirements.*

We develop these principles by first examining the surface structure of the supply chain and identifying problems, issues, and requirements in supply chain design that could arise due to this structure. Next, we develop a schematic or logical meta-model of the chain in order to develop insights about the role of information in the chain. In developing this meta-model, we identify two

principles of separation as the underlying basis for redesign of the supply chain: the principle of separation of requests (demand for service or functionality of supply chain components) from request-satisficers (supply chain actors) (Moshowitz 1997); and the principle of separation of information flows from physical flows (Klobas 1998). Finally we show how ICT-enabled redesign of the supply chain using these two principles can contribute to a cost and value advantage for the supply chains.

## 2 DESIGN DECISIONS FOR A SUPPLY CHAIN

“A supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to the end user as well as the associated information flows” (Handsfield and Nichols 1998).<sup>1</sup> A number of organizations or actors are involved in the supply chain. Physical goods flow sequentially downstream along the supply chain. Information flows, upstream flows of customer orders and downstream flows of shipping information, coordinate the operations of the supply chain.

Design of a supply chain involves four design decisions. These decisions are the choice of actors in the supply chain, governance mechanisms in the chain, structuring (i.e., sequencing order) of the activities in the chain, and the choice of coordination structures in the chain. While some of these decisions are the consequence of the natural production and delivery processes or are strategically fundamental to the chain, other decisions are a matter of design and thus, at least theoretically, under the control of the designer of the supply chain. Moreover, these decisions are interrelated. For example, the choice of a totally vertically integrated governance structure precludes free choice of actors outside the ownership of the firm, while the choice of a market mechanism at every interface between the components of the supply chain would limit the design to dyadic coordination at the supplier-buyer interface.

The first design decision is the level of *dynamism in the choice of actors* in the chain. Static chains are chains where the partners in the chain are relatively established. On the other hand, in a completely dynamic chain the partners in the chain can vary from one market opportunity to another. Dynamism, however, results in increased coordination costs due to costs for actor selection, contract negotiation and specification, and increased monitoring (Moshowitz 1997, 1999). Information technology, by supporting and/or enabling these activities can influence the dynamic selection and inclusion of various actors in the chain (Moshowitz 1999).

A related decision is *the governance decision* that deals with the ownership of various actors in the supply chain. Different actors (or organizational units) may perform each differentiated activity or step in the chain. If all actors belong to the same organization, the chain is vertically integrated. On the other extreme, each actor performing a differentiated activity may be completely independent from others, operating at an arms-length relationship idealized by markets. Transaction cost economics (Williamson 1981) suggests that in those cases where coordination costs between the actors are likely to be high, organizations tend to governance by hierarchy, thus creating vertically integrated chains. On the other hand, vertical integration may mean that not all activities in the chain may benefit through economies of scale and specialization, thereby increasing the aggregate production costs associated with the entire chain. When high production costs are unacceptable and need to be reduced, the governance is by procurement through markets (Clemons and Kimbrough 1986; Malone, Yates and Benjamin 1987). The choice of governance in the chain depends upon the balance achieved between the transaction costs and the production costs inherent in the chain. Use of ICT can influence both production costs as well as coordination costs.<sup>2</sup>

The *structure of the supply chain* (i.e., its sequencing) is usually determined by the natural sequence of activities inherent in the manufacturing and logistics processes. However, often the structure is a consequence of chance, previous history, habit, limitations

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<sup>1</sup>A supply chain also includes financial flows (e.g., payment for goods and services). For simplification we do not consider financial flows in our model. Financial flows are transfers of financial value between actors. While the description is not exactly accurate, financial flows may be considered as information flows between the actors.

<sup>2</sup>IS literature (Clemons and Kimbrough 1986; Malone, Yates and Benjamin 1987) has focused primarily on the reduction of coordination costs through ICT—thereby predicting a move away from hierarchies (vertical integration). However, ICT, especially in the case of information intensive industries, can also reduce production costs. Thus, depending upon the relative effect on coordination and production costs, ICT could lead to either coordination by markets, hierarchies, or relationships.

of the communication media, and limitations of the coordination mechanisms. For example, items such as computer systems may be assembled at the factory or warehouse before they are shipped out to the customer. However, in an alternate scenario, the components such as the monitor, the processing unit, and the printer may be shipped directly from the component supplier to the customer where the assembly may be performed by field technicians or the customer himself. In the former case, the component shipments in the supply chain converge at the factory or the warehouse, while in the latter case they converge at the customer location.

Finally, coordination in the supply chain is based upon the flow of coordinating information (Lee, Padmananhan, and Whang 1997; Tan and Shaw 1998). Through long-established convention, information flows in traditional supply chains have been primarily dyadic (i.e., between the supplier-buyer) and follow the same path as the physical supply chain flows. Thus orders flow upstream from buyers to suppliers, while notification of shipments flow downstream from suppliers to buyers. Again, due to long established custom, as in the cases of bills-of-lading, loading manifests, or airway-bills, the information flows are normally bundled together with the physical flows and travel on the same carrier as the physical shipment.

These customary information flow paths may impose delays, limitations, and constraints that may reduce the efficiency, effectiveness, and responsiveness of the supply chain. For example, a shipping manifest that arrives with the ship means processing delays at the wharf while the shipping manifest documents are delivered and processed by the various authorities before the goods are released and the unloading sequence can be planned and unloading proceed. Or consider a coordination situation where each actor in the supply chain orders its requirements from its immediate upstream member of the chain. In this situation, dramatically illustrated by the famous “Beer Game,” inbound orders from downstream members serve as coordination input to upstream inventory and production decisions. Lee, Padmananhan and Whang (1997) show that information transferred in forms of sequential orders tends to become distorted and can misguide upstream members in their production and inventory decisions. The uncertainty of the orders tends to increase and distortion and variance accumulates as one moves upstream, creating a “bullwhip effect.” This effect is a consequence of the sequential dyadic communication and coordination structure inherent in the chain and can easily be circumvented if alternate communication and coordination paths are designed and implemented.

### **3. PRINCIPLES FOR ICT-ENABLED REORGANIZATION OF THE SUPPLY CHAIN**

The design of a particular instance of the supply chain, **its surface structure**, is the consequence of deliberate or unconscious choices with regard to each of these four design decisions. The above discussion points out that the surface structure of the conventional supply chain can produce inefficiencies, unresponsiveness, and delays that need to be eliminated or reduced through a radical redesign of the chain. This redesign should include a rethinking of the supply chain governance, a choice of the supply chain actors, redesign of the supply chain structure, and redesign of information communication and coordination structures. In the past, less sophisticated information and communication technologies, together with accidents of history, limited the range of available choices for these design variables. The widespread availability of highly flexible and inexpensive information and communication technologies (ICT) such as the Internet, intranets and extranets, intelligent-agents, global positioning systems, open-EDI standards, electronic markets, e-procurement, and broadband width are creating new possibilities for radical redesign of the supply chain. Rather than examine the individual impact and design implications of each of these technological innovations, in this paper we propose principles of abstraction that can be used to frame the redesign decisions by providing the necessary framework for understanding and exploiting the redesign potential of these and future technological advances.

Information systems development literature suggests that viewing the systems as abstract (or “logical”) entities as opposed to concrete (or “physical”) systems frees the designer from perceived constraints on their creative design processes that may arise due to the current physical structure of the system (DeMarco 1978, McMenamin and Palmer 1984). The surface structure of the supply chain is a physical version of the supply chain. It embodies an implementation instantiation of the chain consisting of a preselected governance structure, a defined, usually fixed choice of actors, a relatively rigid predefined structure, and a defined set of coordination and communication structures. This physical structure may suffer design anomalies that need to be examined and redesigned in order to recreate supply chain designs that meet the customer’s cost and value expectations. Consequently, we need “logicalization” processes that help us view the supply chain and its management at an abstract level unconstrained by existing physical implementation details, thereby creating a greater level of flexibility in redesign of supply chains.

These logicalization processes are built upon two concepts of separation: the separation of “abstract requirements for work” from “concrete satisficers” of the work requirements (Moshowitz 1997) and the concept of separation of “information flows” from “physical flows” (Klobas 1998; Sheombar 1992). Moshowitz characterizes a virtual organization:

In terms of four basic management activities that depend upon separating requirements from satisficers: formulation of abstract requirements; tracking and analysis of concrete satisficer; dynamic assignment of concrete satisficers to abstract requirements in terms of explicit criteria; and exploration and analysis of the assignment criteria (associated with the goals and objectives of the organization). The logical separation of demand-requirements from demand-satisficers allows management to dynamically switch assignment of satisficers to requirements so as to optimize performance on the basis of explicit criteria. (Moshowitz 1997, p. 33)

This problem is the same as the problem of matching supply chain requirements to various supply chain actors (satisficers) under conditions of dynamically shifting demand and supply patterns. The separation of abstract requirements and concrete satisficers and the use of criteria-based switching makes it possible to dynamically allocate the most appropriate actors to different parts of the supply chain requirements.

Both Klobas and Sheombar observe that modern information and communication technologies make it possible to detach information flows from physical flows. This makes it possible for information about a physical flow to arrive before the physical flow itself. This not only makes it possible to anticipate and prepare for the arrival of a physical shipment, it also makes it possible to process the information electronically, in parallel with the transportation of goods. While the former increases the coordination between physical processes, thereby reducing coordination costs and waiting time, the latter reduces the overall cycle-time for the supply chain and increases service quality by reducing information processing delays and information processing errors.<sup>3</sup> Furthermore, now that information flows are not physically attached to the physical goods (and therefore are not required to travel on the carrier of these goods<sup>4</sup>), they can take different paths than the flow of physical goods. This reduces the constraints on information flow-paths, thereby increasing the variety of options available for communication and coordination structures.

Taken together, the two principles of separation suggest a three-layer model for modeling a supply chain as shown in Figure 1.

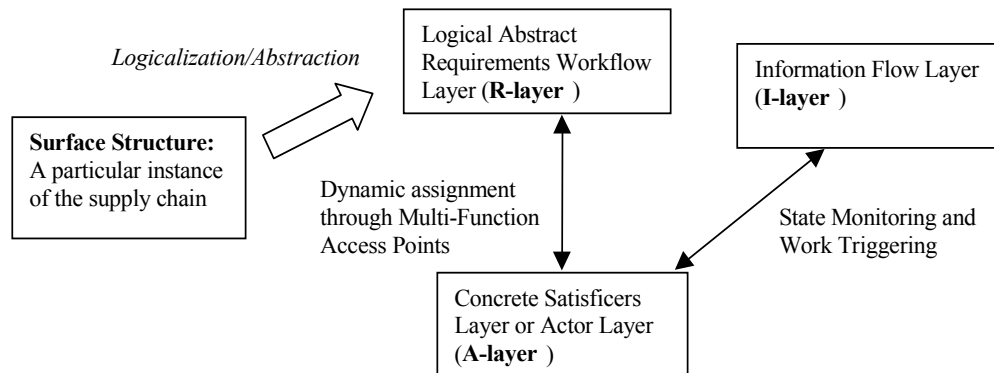


Figure 1. Logical Three-layer Meta-model of a Supply Chain

<sup>3</sup>For example, the literature on EDI recognizes that electronic messages arriving ahead of the physical shipment can be processed in parallel with the transportation time. Furthermore, electronic processing of these messages reduces the possibility of error, thereby increasing the service quality levels.

<sup>4</sup>For example, the airbill attached to the shipment would travel on the airplane together with the shipment.

In the three-layer model, a physical instance of a supply chain is first described in terms of its logical requirements. Logicalization is a process of abstraction in which each activity or step in the chain is described in terms of what needs to be done rather than in terms of the actor or the department performing that activity. The logicalization process includes removing historical, procedural, tool-related, political, and organizational details to arrive at an essential requirement model of the chain (DeMarco 1978; McMennin and Palmer 1981). This logical requirements model (the requirements layer or the R-layer) becomes the basis of a logical redesign of the physical part of the chain. At this level, the chain can be examined for natural sequences of workflow, possibility of parallelization and/or combination of work-steps, and elimination of redundant steps leading to a radical re-engineering of the entire supply chain structure (Hammer 1990; Davenport 1993).

Next, the process of allocation of concrete satisficers from the actor layer (A-layer) to the service needs of the R-layer through switching points can be used to select and assign actors to the requirements of the R-layer (Moshowitz 1997, 1999). The separation of the logical requirements (R-layer) from the satisficers/actors (A-layer) and the use of computer-based dynamic switching systems for allocating satisficers to requirements on the fly would help achieve the required level of dynamism in the choice of actors. Whereas hitherto conventional supply chains were limited to a bounded choice of actors, constrained by bounded rationality (Moshowitz 1997), we now have the possibility of choosing the most appropriate actors/satisficers from a larger set.<sup>5</sup> Under conditions of highly uncertain and shifting consumer demand patterns, the supply chain designer can rapidly redesign, re-configure, and assemble the required actor/satisficer capabilities and capacity on the basis of explicit criteria such as cost minimization, cycle time reduction, and quality requirements. Moreover, the ability to quickly and inexpensively assemble the required competencies makes it possible to provide mass-customized products and services to individual customers on demand.

The separation between the requirements (R-layer) and satisficers (A-layer), together with the separation between the physical flows and information flows (I-layer), also provide us with the flexibility in choice of governance mechanisms. As mentioned earlier, vertical integration implies a fixed choice of actors governed by a centralized hierarchical arrangement. Consequently, in a traditional hierarchy, while physical flow of goods or services is cross-functional, coordination is achieved by hierarchical monitoring and control. In a market arrangement, on the other hand, the actors in the chain are relatively independent and coordination is achieved by dyadic flow of market information along the supply chain between the buyer and the supplier. The separation of physical flows from information flows makes it possible for the chain designer to design topologies for information flows that either follow the physical flow paths or can take independent paths such as leapfrogging steps in the chain or be directed to and from centralized monitoring points. Thus in addition to hierarchy or markets, virtual vertical integration is now possible, opening up the possibilities for a variety of relationship-based and alliance-based governance mechanisms. As information technology can reduce both transaction costs and production costs, depending upon the relative balance between the two costs, the designer can now choose the governance arrangement that truly minimizes the overall chain costs.

The separation between the R-layer, A-layer, and the I-layer also opens up possibilities in the redesign of the physical structure of the supply chain. Logicalization, i.e. abstraction of the logical requirements of the chain into the R-layer, makes it possible to differentiate between the essential and non-essential activities in the chain (McMenamin and Palmer 1984). The elimination of non-essential activities not only reduces costs, it also reduces the cycle-time requirements, thereby increasing the responsiveness of the chain. Moreover, a focus on the essential activities opens up other opportunities for reengineering such as combination, automation, and/or parallelization of various steps in the supply chain (Hammer 1990). This too not only reduces the cost and cycle-time, it also makes it possible to configure the supply chain to meet the requirements for producing customized products and services for individual customers. Finally, the flexibility and variety in the I-layer makes it possible to design information and communication structures that meet the requirements for coordination and control of these varied physical chain structures.

The last design variable is the design of communication and coordination structures. As discussed above, the separation of physical flows from information flows makes it possible to design communication and coordination structures that are independent of the physical paths and the timing of the physical flows. The greater range and reach of information and communication technologies makes it possible to deliver monitoring and triggering information from any node of the chain to any other node of the chain, irrespective of the physical chain structure. This reduces arbitrary constraints on the design of communication and coordination structures, thereby leaving the designer with the freedom to design the most appropriate coordination and control mechanisms.

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<sup>5</sup>“The essence of virtual organization is the systemic ability to switch satisficers in a decision environment of bounded rationality” (Moshowitz 1997, p. 32).

Furthermore, communication structures can now be designed for information sharing such that the upstream and downstream accumulation of information distortion characterized by the bullwhip effect can be eliminated. The anytime, anywhere reach of modern information and communication technologies makes it possible to instantaneously share a variety of relatively rich information across many tiers or actors in the chain in either direction.

Thus the separation of the R-layer, A-layer, and I-layer opens up a variety of configurations and design choices that were not easily available and implementable in conventional supply chain designs. This flexibility in redesign of the R-layer, the allocation of concrete satisficers of actors from the A-layer to the R-layer, and in the design of information flow paths and timing (I-layer), taken together, provides the chain designer with a variety of design options for the choice of actors, governance mechanisms, chain structure, and coordination structures in the chain. Choices appropriate to the demand patterns lead to lower costs, quicker response times, appropriate quality, and appropriate levels of product and service customization.

#### **4. SUMMARY AND CONCLUSIONS**

The primary contribution of this paper, therefore, is to develop general principles for ICT-enabled redesign of supply chains. Rather than examine the individual impact and design implications of each new technological innovation, in this paper we propose general principles of abstraction that can be used to frame supply chain redesign options and decisions. These principles provide the necessary framework for understanding and exploiting the redesign potential of current and future technological advances.

We need to recognize that in this paper we have taken a somewhat limited, rational view of the supply chain redesign and reconfiguration process. We should not lose sight of the fact that the dynamic supply chains/supply webs conceived in this paper are “human activity systems” consisting of a number of relatively independent organizations. Each member of the web, in addition to being interested in the collective survival and collective advantage of the web, is also likely to be interested in individual survival and his or her own competitive advantage. This raises a number of questions that, while beyond the scope of this paper, nevertheless, are key to the success of the redesign effort. For example, if we assume the existence of a supply chain designer, or “lord of the chain,” without going into the question as to who or what parties are likely to play this role, it is unlikely that an acceptable design or a successful implementation of that design will be achieved. Another such question is the apportionment of benefits (and costs or pain) derived from the redesign of the supply chain. Perceived fairness in the apportionment of benefits and pain will be another important factor in the acceptance of the new supply chain designs. Such questions are usually answered based upon the issues of exercise of power and trust relationships in the supply web (Kumar, van Dissel and Bielli 1998). Thus no principles for a radical redesign of the supply web are likely to be complete without consideration of power, trust, and relationships in the web. Further research in supply chain/supply web redesign principles also needs to consider and incorporate these “softer” design principles.

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