Computer Integration: A Co-Requirement For Effective Inter-Organization Computer Network Implementation

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ABSTRACT

Inter-organization computer networks (IONs) provide significant opportunities for improving coordination between firms engaged in mutually dependent activities. This research paper focuses on how IONs affect information processing requirements, and production and transaction costs when they interconnect firms with internally integrated computer systems and when they are used only as substitutes for conventional media. We conclude that significant improvements in inter- organization coordination result when IONs support exchanges between internally integrated firms. However, while IONs reduce production costs, they can simultaneously increase transaction costs including those associated with penetration into another firm's computing resources, and segmentation in the marketplace.

1. INTRODUCTION

The use of inter-organization computer networks (IONs) provides opportunities to improve efficiencies for firms engaged in mutually dependent activities.

The extent of improvements in coordination, however, is contingent the degree of computer integration within participating firms. Without internal computer integration, IONs are used as substitutes for conventional media. With internal integration, ION use facilitates access to resources within the participating firms. ION access can affect changes in communication patterns between firms, such as the scope (breadth) of information exchanged, penetration (direct access) into other firms' systems, and segmentation (non-universal access to these resources) [Estrin, 1987]. These shifts in patterns not only provide significant opportunities for improving coordination, but introduce complexities into network implementation that have important organizational implications.

The purpose of this paper is to provide a theoretical context for understanding the importance of internal computer integration as a co-requirement for effective ION supported coordination, and describe developments in integration within a small group of companies.

This paper represents part of the research findings of an exploratory investigation on design and manufacturing applications of ION use in the semiconductor industry. A select group of firms comprised the sample for our study in an industry where the diffusion of ION adoption is at an early phase. We found that at the present time IONs are used primarily as substitutes for conventional media, and, that there is a range of variance across firms in the development of computer integration and use of IONs to support exchanges between integrated systems.

Semiconductor production involves the design and development of a variety of circuits devices, including semicustom products. These semicustom products require fast turn around times, and product delivery of all types of semiconductors must be accompanied by the results of complex inspection and test data. Our research will be useful for firms in other industries that share these critical attributes.

The following section provides a theoretical framework for understanding the role of new information technologies and their effect on information processing within organizations and on inter-organization relationships. This is followed by a very brief description of the research methodology and setting (the process of developing semiconductors) for our study. The next three sections provide examples of integration that illustrate the benefits of this co-requirement for effective ION adoption. The paper concludes with a discussion on the examples and the theoretical framework.

2. INFORMATION PROCESSING AND INTER-ORGANIZATION RELATIONSHIPS

The affect of computer networks on organization design can be understood by focusing on the importance of effective information processing within and between firms.

2.1 Information Processing

Organizations can be defined as information processing systems. The tasks performed by individuals in organizations involve acquiring, interpreting, generating, assessing, distributing, and storing information [Weick, 1979]. The pattern of relationships between individuals performing these tasks define the organization structure [Thompson, 1967]. Effective structures are those that ensure optimum coordination by allowing adequate information exchange between organization units to reduce uncertainty [Galbraith, 1977]. Effective organizations are those whose information requirements match their information capacities [Tushman, Nadler, 1978].

Information capacities are integrating mechanisms adopted to support internal information exchange between appropriate individuals, subgroups, or groups within the organization (e.g., product teams, organic and mechanistic structures, and so on). Recently [Adler, 1989] found that in the electronics and aircraft industries, CAD/CAM activities are integrated through a variety of mechanisms that range from direct contacts, liaison roles, task forces, and cross functional committees, to tighter mechanisms such as CAD/CAM managers and central CAD/CAM organization units overseeing all activities.

Telecommunication and computing innovations, in general, are technological integrating mechanisms that will have an increasingly significant influence on organization design in the future. In the research just cited, for example, Adler (1989) also found that the requirement that CAD and CAM design specifications fit a common database, and that developers be able to communicate with the common database, were powerful integrating mechanisms.

In particular, computer networks, which provide the means for automatically interconnecting data stored in separate computing systems, offer the possibility for improving the efficiency of information flows and are very important integrating mechanisms [Morgan, Lach, Bushnell, 1990] Indeed, the full benefits of computing technology can only be realized when systems are integrated [Office of Technology Assessment; 1984]. Moreover, the decisions involving computer integration are qualitatively different than decisions involving computer acquisitions because they imply a new approach to organizing [Majchrzak, Nieva, Newman; 1986]. The challenge of re-organizing involves reassessing the information requirements of the firm in light of the technical capacities of network systems. Because the technical attributes will affect the way that information is conventionally processed, network adoption and implementation, in turn, will affect the tasks performed by individuals. Since the pattern of relationships among individuals is defined by the information processing tasks they perform, the adoption of computer networks (or any technological innovation that changes the way information is processed) shifts organization structures. The focus of this paper is not on structural change [Hart, Estrin, 1990b], but rather the requirement and benefit associated with reassessing information needs when adopting computing networks. Overall, information reassessment should be viewed as a component of network implementation that has important ramifications for organization structures.

2.2 Inter-Organization Coordination

We assume that what is true of intra-organization units is also true of inter- organization units. Namely, the role of integration mechanisms, such as computer networks, will reflect attempts to ensure optimum coordination in the pursuit of mutually dependent activities. But organization behavior researchers have not paid a great deal of attention to the role of information technologies as potentially significant factors in the flow of resources between firms. In general, inter-organization literature has focused on the significance of certain resources for the survival of particular organizations [e.g.,Hannan, Freeman, 1977; Aldrich, 1979], the strategic arrangements necessary to ensure access to those resources [e.g., Pfeffer, Salancik, 1978], and the type of interdependence between firms based on their core technologies [e.g.,Victor, Blackburn, 1987; Thompson, 1967].

One of the reasons for the lack of attention given to the impact of information technologies is that resources have conventionally been defined as elements with tangible properties (i.e., money, customers or clients, physical facilities, materials, etc.), and information as the exchange necessary to ensure the acquisition and flow of these resources [e.g.,Van de Ven, 1976; Levine, White, 1961]. More recently, recognition of the importance of information as a resource in itself [Beniger, 1986; Paisley, 1980, 1985; Porat, 1977; Bell, 1973; Machlup, 1962], has encouraged greater interest in: (1) how the acquisition of information from the environment can result in internal organizational transformations [Huber, Daft, 1987; Huber, 1984; Adams, 1980], and (2) how the transformation of information through the use of information technologies, increases the value of information and improves information processing activities [Huber, 1990; Kanter, 1990; Rice, 1987; Johnson, Rice, 1987; Keen, 1986; Wiseman, 1985; 1988].

The most important reason for selecting the semiconductor industry as the focus of our research is that firms involved in the development of integrated circuits are information intensive. That is, a significant resource of the organization is information in form of complex circuit designs and the technical information required to accurately produce semiconductors.

2.3 Use of IONs To Improve Coordination Between Organizations

The improvements associated with the adoption of IONs are based on the potential opportunity to reduce production and transaction costs associated with inter-organization coordination [Hart, Estrin, 1989; Child, 1987; Ciborra, 1987; Malone, Yates, Benjamin, 1987; 1989].

Following the information processing model proposed by Galbraith [1977], production costs decrease when coordination is improved. Coordination reduces uncertainty, that is "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" [Galbraith, 1977, p. 36]. Since the critical dimension is the amount of information that must be exchanged, we would expect that IONs, which increase the speed and amount of information that can be transferred between firms relative to other media, would improve inter-organization coordination.

Transaction costs are *ex anti* costs involved in developing and securing contracts, and *ex post* costs incurred when initial contract agreements are not met and either expectations must be adjusted or deliverables corrected [Williamson, 1975, 1985]. The uncertainty associated with the impossibility and cost of enumerating all the possible contingencies and appropriate adaptations is one dimension of transaction costs. Another is asset specificity, or the durable investments that are transaction specific and have certain "lock in" effects on future relations between participating firms [Williamson, 1971]. Since IONs provide the means to exchange data quickly between geographically distant locations, we would expect that their use would improve the ability of partners to address contingencies when they occur, and eliminate or reduce certain asset investments. In these respects, IONs would contribute to reducing transaction costs.

2.4 Research Question

We address the following question: How do IONs affect information processing requirements, and production and transaction costs when they interconnect firms that are internally integrated in contrast to when they are used only as substitutes for other media?

3. RESEARCH METHODOLOGY AND CONTEXT

Eighty-two interviews were conducted in twelve organizations, seven semiconductor firms and five merchant photomask shops during an 18 month period, from January, 1988 to July, 1989. Priority was given to selecting firms involved in the development of semicustom products. Application specific integrated circuits (ASICs), a major subset of logic devices, are semicustom (or in some cases custom) devices in contrast to off- the-shelf products (i.e., memory, microdevices, and linear devices). The design phase of ASIC development requires greater interaction between customers and vendors, which may be facilitated by IONs.

The individuals interviewed included circuit design engineers, circuit design tool developers, managers and supervisors of the various production phases and customer service areas, production control managers, and personnel responsible for computer and network systems. Our inquiries provided descriptions about the present and anticipated use of computer networks, both of which were incorporated into our analysis.

The interactions between firms that are supported by IONs occur between (1) ASIC customers and ASIC producers during the design phase, (2) producers of all types of semiconductor products and photomask shops, and (3) producers of all types of semiconductor products and their customers during the manufacturing phase. More details concerning the nature of these exchanges, the information processing requirements of firms involved in semiconductor production, the extent of ION adoption in the firms visited, and other theoretical issues that emerged from our investigation can be found elsewhere [Estrin, Hart, 1989; Hart, Estrin, 1989, 1990a, 1990b].

Briefly, it is important to note the following about the process of semiconductor design development and production. ASIC designs are increasingly being developed by customers in-house. This requires investment in workstations and acquisition of design tools through license contracts. These tools are libraries of circuit components. They are increasingly being made available by ASIC producers, providing conformity to fabrication requirements, and thus representing an important interface between design and manufacturing activities. Exchanges between ASIC customers and producers involve transferring design tool software and updates, responding to inquiries from design engineers in customer firms, merging databases generated by individuals performing parallel design tasks in different locations, and transferring design databases and simulation results between firms.

Photomasks are the glass plates containing the geometric design patterns; they are the hard copy of the CAD circuit design. Photomasks are produced by either merchant mask shops or captive shops, but the interactions between the semiconductor producer and shop are identical regardless of the shop type. These exchanges involve transferring the design database, the mask order information, and technical instructions that will be used to generate a software program called a job deck. The job deck drives the electron beam (e-beam) equipment used to expose the patterns onto the glass plate. After the plate is exposed and developed, a series of sophisticated and expensive inspections are performed. These assess the integrity of the pattern lines, whether the patterns conform to the design database, and are placed onto the glass plate correctly. Inspection results are transferred to the customer along with the photomasks. In addition, throughout photomask production, order status is routinely exchanged between the two firms.

Finally, the interactions between semiconductor producers and their customers are similar insofar as test results (i.e., quality assurance and reliability information) must be transferred, as well as information necessary to coordinate production control schedules in the customer firm. Conventionally, test information for standard products is printed and distributed to customers who use the data to match their own technical requirements with available products.

4. ION USE AS A SUBSTITUTE FOR CONVENTIONAL MEDIA

Among the firms we investigated the most well developed use of IONs supported the transfer of design databases from semiconductor producers to photomask shops. ION substitution for magnetic tapes contributed to improving turn around time for products with tight production schedules such as ASICs.

ION use is particularly effective in saving time when design databases must be physically transported across international boundaries -- often resulting in inspection delays in customs offices -- or, when portions of a database must be resent to the mask shop because the original contains errors that need to be corrected by design engineers. IONs are also used to more effectively manage job loads in photomask firms with production facilities in different and distant geographic locations. When one shop is overloaded, orders can be more efficiently handled by other shops when exchanges are supported by IONs.

Estimates by individuals in various firms indicate that, on average, three days are required to physically transport a magnetic tape from a design center in the Orient to a production facility in the U.S. Databases transferred within the continental U.S. via couriers providing same day service reach the production facility within six to nine hours. However, failure to meet same day deadlines or 24 hour service results in costly delays for mask shops operating on a 24 hours basis.

5. ION IMPLEMENTATION AS A CATALYST FOR INTEGRATING SYSTEMS

Although IONs improve coordination when they are used as substitutes for other media, the potential for greatest improvement is associated with the co-requirement of integrated systems. And, the greater the integration, the greater the opportunity for selecting specific information that can facilitate inter-organization coordination.

5.1 Internal Integration -- Circuit Design

Circuit design development involves a series of steps, which are typically performed by individuals working on separate workstations or computing systems. These steps involve: (1) developing a schematic, (2) translating the schematic into a logic diagram of circuit components, (3) placing and routing the components, and (4) conducting performance simulations which are run at increasingly higher design levels to test whether the design meets specifications.

Internal computer integration supporting these design activities facilitates the efficient exchange of design databases to appropriate systems along the chain of design tasks. This is especially important when the systems supporting certain tasks are in geographically distant locations.

The benefits of integration increase when designing semicustom devices, particularly devices based on standard cell designs. Unlike gate-array designs, the selection and placement of the components for standard cell designs are unique. (For gate-arrays, in contrast, which comprise the largest segment of the ASIC market at the present time (roughly 50%) only the interconnections, or routes, between components are unique.) When a design engineer may need a component to match certain specifications and the component is not available in the local design tool library, computing networks allow engineers to access these components quickly. Moreover, since new components are continually created, networks allow ready access to virtually entire libraries held by a firm, without requiring that all components be held locally and routinely updated. In addition, the networks make it possible to use the computing resources of other firm facilities around the globe for time-consuming simulation runs when local resources are overloaded. This is especially useful in the case of ASIC devices which have short turn around requirements.

A few of the semiconductor firms we investigated supported highly integrated design systems, although each of the firms supported some degree of internal integration. On the other hand, we found limited use of IONs for database exchanges with customers involved in in-house ASIC design. Reasons for the limited use of IONs included lack of bandwidth availability and cost/benefit ratios given the amount of current exchanges between firms. Individuals interviewed maintained that IONs would be used when the exchanges between customers and producers increased to a level that made the cost of conventional media more expensive than computer networks. That point in time may come when, as anticipated by analysts, the market share of standard cell based designs (currently at roughly 20%) increases, inviting the potential for greater interaction between circuit producers supplying design tools and ASIC customers.

5.2 Internal Integration -- Photomask Production.

The following is a scenario that describes the benefits that can be achieved through internal computing integration in a photomask shop. The scenario is based on data gathered from three merchant photomask shops and one captive shop involved in the process of developing internal integration.

An automated production control system, that is integrated with systems supporting various manufacturing processes, improves the tracking capability of mask development at each stage of production. Integration allows multiple individuals access to current product control information, facilitates the ability of customer service personnel to respond to inquiries about product status, and more conveniently supports scheduling and rescheduling mask orders. Inspection systems (for checking defects, making die to database comparisons, and inspecting registration) that are networked with systems supporting relational databases provide the capability for correlating multiple inspections and providing customers with specifically requested inspection results. Like the independent inspection systems, the e-beam photolithography equipment is computer-based and generates a battery of performance data irrespective of whether it is retrieved and used. When certain data (e.g., the e-beam room temperature and e-beam drift) are correlated with results from the inspection systems, performance of the e-beam equipment can be used to predict mask quality and thus reduce the number of inspections required. When these systems are networked with the production control systems, tighter scheduling control is gained. Moreover, networking these systems with business databases provides the capability for correlating size and geometric specifications with yield to predict cost.

One of the most significant advantages for photomask customers involves the integration of the systems that support mask inspections. Computer-based inspection systems generate a large amount of data that currently is not transferred in a way that enables the customer to use the data effectively. When inspection systems are networked to a relational database in the photomask firm, data can be retrieved by customers via IONs. Online access to this data provides customers with information that eliminates the need for redundant inspections often performed by customers after the mask has been delivered. These inspections are both time consuming and expensive.

Similar network applications in semiconductor firms can eliminate the need for semiconductor customers to perform reliability tests. One semiconductor producer indicated that when reliability data can be retrieved from the producers' databases, the qualification cycle for new products performed at the customer site (which takes from six to nine months or more) can be eliminated.

5.3 Internal Integration -- Integrating Design Database Preparation and Photomask Production

As indicated earlier, the design database transferred to the photomask shop is accompanied by a set of technical instructions used to create a software program that will run the photolithography equipment. The following is a description of one semiconductor firm's innovative procedure for generating the software program, in-house and transferring the program via IONs to their photomask vendors. The example demonstrates the benefit of streamlining information through internal integration among participating firms.

The semiconductor firm initiated the practice of creating its own job decks in 1985, and in mid-1988 had installed an automatic job deck program. Design engineers now feed technical/hierarchical/placement information into the program which automatically matches the circuit design with a design frame. A frame is required for each design database and contains manufacturing related information and test patterns. (An automatic frame generator has also been installed which computes the optimum wafer size.) The automatic job deck program allows the firm to program the e-beam equipment to write masks from hierarchical databases, alleviating the necessity for the time consuming process of flattening hierarchical databases. This contributes to reducing database preparation otherwise performed by personnel in the photomask shop prior to e-beam write. Moreover, since the job deck contains all of the information required to process a photomask order, a separate order entry process at the semiconductor firm is eliminated.

The internal integration that supports the efficient flow of data allows the semiconductor producer to eliminate certain contracted services from their photomask vendors. The photomask shops, in turn, will benefit--in time--from the streamlining initiated by the semiconductor firm when they adopt automated order entry systems designed to retrieve the relevant order entry data from the job deck program created by the semiconductor firm. Under the current arrangement, mask shop personnel must retrieve the appropriate data from the job deck, and manually reprocess the order according to the firm's local standard.

6. REASSESSING INFORMATION PROCESSING REQUIREMENTS

These examples of internal computer integration represent a series of decisions involving the information necessary to efficiently and effectively complete certain tasks required to design and produce integrated circuits. IONs are not only a means used to facilitate the exchange of information between firms, but a catalyst in streamlining the flow of information within the organization. The decisions resulting in information processing improvements when computer networks are implemented are similar to those made when computers, or computer upgrades, are implemented. However, in the case of networks the scope of the information reassessment is greater, having more ramifications in terms of organization design.

When an organization adopts a single computing unit to serve multiple individuals, implementation requires an evaluation of what information needs to be processed by the unit. A successful evaluation matches the capacity of the unit with the information processing requirements of the tasks that need to be supported.

On the other hand, the implementation of a system of networked computers requires an assessment of the organization as an information processing unit, and is less restricted by the technical limits of the computer unit. The successful evaluation results in the selection of the most parsimonious amount of information required to optimally perform tasks performed in multiple areas of the organization.

The implementation of IONs increases the scope even further. The assessment of information requirements must incorporate the relevant information processing requirements of participating organizations. The results of an evaluation conducted in one organization affect the information processing requirements of other organizations. The potential impact on the information processing requirements of each organization increases with the number of participating firms, reflecting greater need for standardization.

7. PRODUCTION AND TRANSACTION COSTS

The descriptions provided also indicate that certain production costs are reduced when IONs are used as substitutes for conventional media as well as to link integrated systems. IONs reduce the uncertainty associated with production costs. As substitutes for magnetic tape, IONs narrow the gap between the data available and the data required to develop circuit designs and produce photomasks. In addition, by providing access to integrated systems generating inspection and test data, IONs contribute to eliminating redundant tasks performed by customer firms.

When IONs are used as substitutes and to link integrated systems, they also contribute to reducing transaction costs associated with uncertainty and asset specificity. Transaction uncertainty is the inability to know future contingencies that may be required to fulfill contracts. By facilitating the transfer of corrected design databases to photomask shops, IONs reduce *ex post* transaction costs. They provide greater capability for addressing unforeseen contingencies. In addition, IONs reduce site specificity by providing engineers working on ASIC designs in-house access to the cell designs stored in geographically distant locations.

On the other hand, IONs can increase transaction costs while simultaneously reducing production costs. Greater transaction costs are associated with the shifts in communication patterns resulting from ION adoption indicated earlier, specifically penetration, or access into other firm's computing resources, and segmentation. They are the result of new dependencies on computing resources, or information generated on those resources, outside the boundaries of a firm's conventional control.

For example, online access to production control systems provides valuable information that allows customers to improve their scheduling capabilities. Dependence on the vendor's permission to access information that directly improves production efficiencies represents a new dependence, or cost for the customer. On the other hand, ION supported access to this information also creates a new vulnerability for the vendor. If the priority of a customer's order is downgraded, even without jeopardizing the order deadline from the producer's perspective, customers may make the producer accountable for the change in status. Online access can make internal decision-making more visible to other firms, thereby introducing the vulnerability of having internal activities overseen by outsiders.

Briefly, another example involves the new dependence for photomask inspection and semiconductor test data generated outside of the conventional overview and control of the customer. While online access to this information represents a new dependence for the customer, the vendor also faces security related vulnerabilities when allowing outside firms access to internal systems to retrieve inspection and test data, or other information stored within internal systems.

Other transaction costs are associated with the investment in learning the software tools used by engineers to design circuits (human asset specificity), and the "lock in" effect that use of proprietary tools have on customer flexibility in choosing producers. The use of proprietary design tools contributes to market segmentation, a condition that is intensified by the use of IONs which tightens inter-organization coordination. Also, *ex ante* transaction costs are increased for vendors that must cover the cost of transmission lines and computer resources needed to support ION exchanges when investments in these dedicated assets are required to establish and maintain contracts.

In summary, we draw the following two primary conclusions. First, while certain production and transaction costs can be reduced when IONs are used as substitutes for conventional media, very significant improvements in inter-organization coordination result when IONs support exchanges between internally integrated firms. Secondly, while ION use supported by computer integration reduces production costs, they can simultaneously increase transaction costs. Moreover, the vulnerabilities, or costs, that result from penetration and segmentation are new dimensions of contract costs that are not included in current descriptions of the transaction cost perspective.

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