PRACTICE AND EXPERIENCE

Inter-Organization Networks, Computer Integration, and Shifts in Interdependence: The Case of the Semiconductor Industry

PAUL HART
Florida Atlantic University
and
DEBORAH ESTRIN
University of Southern California

Inter-organization computer networks (IONs) provide significant opportunities for improving coordination between firms engaged in mutually dependent activities. A field study of the use and impact of IONs in the semiconductor industry is presented in this paper Eighty-two interviews were conducted in twelve firms (seven semiconductor producers and five merchant mask shops) providing data on current as well as anticipated ION use. We found that greater efficiencies are possible when IONs are used as substitutes for conventional media. But more effective ION use is achievable when internal computer integration within participating firms is implemented. The implication of this otherwise straightforward observation is that firms using computer networks only as a substitute for conventional methods of exchange will not achieve the degree of inter-organization coordination IONs can support However, while IONs improve coordination and reduce some production and transaction costs, they simultaneously increase certain costs associated with establishing and maintaining contracts with customers. These costs are new dependencies. Dependencies emerge from using IONs to access computer resources, and information generated by those resources, located in other firms. In this way IONs increase interorganization coordination and vulnerability simultaneously. The long term implication of ION adoption is that their use shifts the nature of interdependence between participating firms

Categories and Subject Descriptors: B 7.1 [**Integrated Circuits**]: Types and Design Styles—*gate arrays, standard cells*; C.2.3 [**Computer-Communication Networks**]: Network Operations—network management; C.5.m [**Computer System Implementation**]: Miscellaneous; H 4.3 [**Information Systems Applications**]: Communications Applications—*electronic mail*, J 7 [**Computer Applications**]: Computers in Other Systems—*consumer products*; K.4.3

Funding provided by the National Science Foundation, Presidential Young Investigator's Award, and matching funds from the Lehigh Center for Innovation Management Studies.
Authors' addresses: P. Hart, Computer Information Systems and Decision Sciences Department, College of Business, Florida Atlantic University, Boca Raton, FL 33431. D Estrin, Computer Science Department, University of Southern California, Los Angeles, CA, 90098-0782.

[**Computers and Society**]: Organizational Impacts; K.6.1 [**Management of Computing and Information Systems**]: Project and People Management—*systems development*

General Terms: Management, Performance

Additional Key Words and Phrases: Computer Integration, Inter-Organization Computer Networks, Inter-Organization Relationships

1. INTRODUCTION

Inter-organization computer networks (IONs) have increasingly been adopted to improve coordination between firms engaged in mutually dependent activities. Our exploratory investigation provides evidence of how coordination is achieved. This evidence suggests that IONs have additional impacts on internal computer integration, interdependence between participating ION partners and transaction costs.

Over the past fifteen years IONs has been addressed by a number of scholars [3–6, 8, 9, 12, 25, 26, 28, 31–34, 38, 49]. However, empirical research on the use and impact of IONs is only now beginning to emerge [27, 35, 42, 48]. The focus of these studies reflects interest in electronic data interchange (EDI) currently applied to *business-related transactions*. By contrast, our research focuses on the use of IONs to support *exchanges related to design and manufacturing activities*—sometimes referred to as the next frontier of EDI [36].

The design and manufacturing context introduces a higher level of complexity into computer network exchanges compared to inter-organization business transactions. For example, the greater amount of data and greater sophistication of technical data increases the probability of error; the greater number of computing systems supporting different process applications increases the options for improving coordination; and the greater range of sequential tasks provides more opportunities for extending coordination and thereby increasing productivity.

The focus of our exploratory investigation was the use of IONs among a select group of firms in the semiconductor industry. The initial adoption of IONs to support design and manufacturing activities in the semiconductor industry began around 1985. Overall, however, the rate of adoption has been slow.

Some of the inhibitors to faster paced early ION adoption also accounted for our interest in this technology. ION implementation necessitates reexamining the way information is processed within organizations. They also introduce access to new information resources inside other organizations' boundaries, which impact relationships among participating firms. *Thus, the implementation of IONs, which are adopted to improve coordination between firms and reduce uncertainties related to information and product flow, may also be characterized by the introduction of a new set of uncertainties directly related to ION technology.*

Our study was exploratory in two respects. First, our intent was to identify the exchanges between customers and providers, and whether these exchanges were supported, or could be supported, by IONs. Second, we were interested in how users described both experienced and anticipated effects of IONs, so that we could apply this data to theoretical issues that might be useful in supporting further empirical work.

We found that ION implementation can contribute to a variety of benefits associated with increased coordination and result in shorter product turnaround time. These benefits range from the ability to transfer large databases between geographically distant sites, to greater monitoring capability of product flow and the elimination of redundant and time consuming tasks.

We also found that effective use of computer networks for exchanging information between firms is related to the extent of internal computing integration within firms. The greater the integration, the greater the opportunity for selecting specific information to facilitate inter-organization coordination. The implication of this otherwise straightforward observation is that firms using computer networks only as a substitute for conventional methods of exchange will not achieve the degree of inter-organization coordination that networks can support.

In addition, we found that while network adoption is motivated by certain opportunities, there is a corresponding vulnerability for each opportunity. Each opportunity-vulnerability dyad represents a potential shift in the interdependence between customer and vendor firms. Vulnerability increases with internal integration in the same way that opportunities increase.

Our study should be useful to researchers whose theoretical interests involve the use of inter-organization networks for strategic purposes, the implications of computer-mediated communication and computer supported work, and the effect of electronic networks on inter-organization relationships.

Sections 2 and 3 provide a theoretical context for our study. Section 4 explains our methodology. This is followed by a brief description of the semiconductor design and manufacturing process in Section 5 and a discussion of the ION-related benefits associated with media substitution and computer integration. Section 6 focuses on the implications of IONs for inter-organization interdependence.[1] Finally, Section 7 describes the use and impact of IONs in the context of Porter's [37] "value chain."

2. COORDINATION AND INTER-ORGANIZATION COMPUTER NETWORKS

Organizations can be described as information processing systems. Organization effectiveness is positively related to the capacity of the system to ensure that information required to perform tasks in any given unit is available to that unit [18]. Coordination is achieved when information capacities match information requirements [47]. The greater the capacity to channel information to appropriate units, the greater the coordination and thus the more effective the organization.

[1] Portions of this work were reported previously by the authors [16, 20, 21, 22].

Information capacities are integrating mechanisms adopted to support information exchange between appropriate individuals, subgroups or groups. Examples include product teams, liaisons, task forces, cross functional committees and so on [18]. Telecommunication and computing innovations, including computer networks, increasingly function as important integrating mechanisms within organizations [2, 41]. One important motivation for adopting a communication-based innovation is that it satisfies some previously unmet demand. For example, if a firm stands to benefit in some way (e.g., a more competitive market position or greater internal efficiency) by processing information more quickly, then an innovation that improves the speed of information delivery over the existing procedure or technology may be regarded as satisfying a latent or previously unmet demand. To the extent that IONs increase the capacity to process information, resulting in more effective coordination, IONs satisfy a previously unmet organization demand. This implies that understanding an innovation's impact requires an investigation of how an innovation's use changes the way information is processed within, or between, organizations.

The information capacity to affect coordination is a function of the integrating mechanism's attributes [13, 18]. For example, liaisons can contribute to improved coordination by reducing equivocality about organizational goals [14]. Individuals capable of exercising decision-making with a particular set of skills contribute to improving coordination not only by transferring information but by interpreting information as well. In this way, liaisons integrate the activities of the organization. By contrast, machine-based integrating mechanisms, of course, do not have the capacity to interpret information.

The following are "three attributes of integration" related to inter-organization computer networks. These attributes are not necessarily unique to *inter*-organization networks or even *computer* networks. However, they do indicate how computer networks contribute to inter-organization coordination.

2.1 Speed of Communication

IONs allow information to be exchanged more quickly than by comparable conventional media. One source of task-related uncertainty is "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" [18, p. 36). IONs reduce this uncertainty by narrowing the difference between the information required and the information possessed. Because each exchange transaction can take minutes instead of days to complete, partners' information needs can be satisfied in a more timely way. Improved speed of transfer can induce partners to exchange information not previously shared using conventional methods of exchange. Thus, ION implementation may increase the amount of information exchanged between partners over time. IONs also facilitate more precise exchanges. These changes represent an improvement in coordination that affect productivity. Information that reaches appropriate task units in a more timely way provides the opportunity for shortening turn-around time. Greater speed increases integration by drawing tasks more closely together on a temporal basis.

2.2 Unambiguous and Uniform Exchanges

Routine use of IONs to support exchanges between organizations requires that the information transferred be unambiguous and unequivocal. An ION is a "lean" medium when compared to "richer" media that provide a greater range of cues (e.g., voice inflection, visual expression, feedback capability and so on [7, 24, 44]). Following Daft and Lengel's [13] information richness theory, richer media are required when ambiguous or equivocal information must be interpreted. Leaner media are more useful for facilitating the exchange of information whose meaning is clear and unambiguous.

The implication of this theory for ION use is that information exchanged via IONs must match the expectations of electronic partners. These expectations are established through prior arrangements agreed to by the partners. In a pre-ION environment vendors may agree to multiple arrangements with multiple customers. To compensate for the variation, individuals (e.g., sales or order entry personnel or technicians) in the vendor firms must translate information received into firm-specific standards.

In an ION environment, computer software may compensate for the variation. But the most efficient exchange of information requires that the sequence, format and content of transactions between firms be consistent (i.e., standardized). The importance of this consistency increases with the number of ION partners. Thus, while certain efficiencies in processing information are supported by computer-based automation, greater efficiencies are achieved when information is preprocessed uniformly across ION partners.

The implications of these preprocessing requirements are significant for managers. Information generated and maintained to support tasks within each organization must be reevaluated and modified. This implies reinvestment or initial investment in computer software, changes in task requirements and even shifts in organization structures [41, 45, 52]. Since organizations are information processing systems, the requirement to conform to newly established information processing standards necessarily results in system realignment.

The gradual development of standards since the mid-1980s (i.e., the American National Standards Institute's X.12 and EDIFACT's standards) for EDI support of business related transactions has been an important factor in ION adoption. The establishment of standards for technical information involving design and manufacturing exchanges is more complex and less developed, which may, in part, explain the slower diffusion of IONs in these latter contexts.

In sum, while ION implementation does not require information-related standardization, greater efficiencies are achieved when uniform information processing is established between ION partners. This means that IONs can contribute to increasing interorganization integration by eliminating certain firm-specific procedures, thereby more closely aligning tasks performed in different organizations.

2.3 Reciprocal Interdependence

Among the capabilities that IONs support are file transfer and remote login. These capabilities allow access to resources outside one's organization and reflect the increasingly permeable nature of conventional boundaries [15]. IONs provide access to use of computing resources, use or distribution of proprietary software, access to another organization's databases or technical experts (i.e., through electronic mail). IONs increase integration by providing access to greater resources in other organizations. These resources may compensate for the lack of resources in one's own firm (and thereby eliminate additional investments), provide the capability to offset outside contracting and the means to achieve new efficiencies in manufacturing processes.

This final attribute is the consequence of either one or more of the technical capabilities indicated above. When tasks are separated over time and by firm-specific procedures and access restrictions, interdependence between organizations can be characterized as sequential, following Thompson [46]. Completion of one discrete output is required to proceed along the production process. Interdependence is serial and the order well specified [46].

By improving the speed of communication between geographically distant locations, feedback time is reduced and the possibility of convenient iterations between parties engaged in complementary tasks is introduced. More discrete tasks carried out by different organizations now become stages along a more seamless process. And, by allowing access to shared resources, the contributions of partners are more appropriately characterized as reciprocal and interleaved. Task chains that were once performed by a single firm may be broken up according to the expertise and resources of collaborating firms. This means that as IONs function as integrating mechanisms, their use results in a shift in the relationship between vendors and customers from sequential to reciprocal interdependence [1, 43], that is "the outputs of each become inputs for the other" [46, p.55].

3. COSTS AND INTER-ORGANIZATION COMPUTER NETWORKS

While IONs affect coordination, changes in coordination, in turn, affect costs. The transaction cost perspective [50, 51] provides a useful theoretical framework for understanding the impact of information technologies [10], and IONs in particular [31], on the relationship between coordination and cost.

According to Williamson [50, 51] transaction costs determine whether markets or hierarchies constitute efficient governance structures. When transaction costs incurred in open markets are too high, vertical integration results to reduce these costs. Transaction costs are "the comparative costs of planning, adapting and monitoring task completion" [51, p. 2). These include coordination costs that involve communication and exchange between firms necessary to coordinate production tasks [29, 30]. The advantage of hierarchies, or vertical integration, is that adaptations in transactions can be made "without the need to consult, complete, or revise interfirm agreements" [51, p. 78], and thus minimize transaction costs.

IONs provide the opportunity to reduce transaction costs by facilitating the coordination required to complete interdependent tasks carried out by separate firms. The importance of IONs and their contribution to reducing transaction costs implies that ION adoption may be positively related to the use of markets rather than hierarchies [31]. While our investigation does not address this hypothesis directly, we do provide evidence of how IONs can affect transaction costs in one target industry.

Reductions in transaction costs, reflecting improvements in coordination associated with ION integration, represent positive change. Negative changes are vulnerability costs, reflecting "the unavoidable costs of a changed situation that are incurred before the organization can adapt to a new situation" [29, p. 1319]. Examples of vulnerability costs associated with ION integration may include the costs of adopting specialized procedures, erosion of control over internally generated information and capital costs borne by one ION partner to induce another firm to use IONs. Also, since electronic integration results in tighter coupling among task units, a network-related breakdown makes the system as a whole more vulnerable. Vulnerability costs are unavoidable in the sense that they are incurred at the same time that the benefits associated with greater efficiencies are obtained. Reduced transaction costs and increased vulnerabilities costs are both the consequence of opportunities provided by IONs to integrate information processing activities of two or more electronic partners.

Vulnerability costs notwithstanding, the benefits associated with ION supported integration (i.e., reduction in transaction costs) provide an interesting point of comparison with respect to vertical integration achieved by acquiring another firm. Following Williamson, if acquisition of a firm is associated with the elimination of the need to change interfirm arrangements that apply to information processing, then the level of integration achieved may be regarded as wanting. The changes in information processing procedures and the investment in computing hardware and software to support complementary tasks in different organizations are a means, not an obstacle, to achieve full integration. In other words, *if one firm acquires another firm to improve control and reduce dependence on an external unit, and the acquired firm disregards the significance of revising the information processing procedures, then the level of integration achieved may be less than that of two autonomous firms whose integration is the result of fully implemented IONs.* The new efficiencies that can be achieved through IONs suggest the importance of the proposition, as noted above, that their use could reinforce markets over hierarchies as efficient governance structures. And again, while our investigation does not generate data that directly supports this hypothesis or its alternative, the significance of our work, and future work, can be appreciated within the context of the proposition.

4. METHODOLOGY

During an 18 month period, from January, 1988 to July, 1989, data were gathered in 82 interviews conducted in twelve organizations (seven semiconductor firms and five merchant photomask shops).

Because of the exploratory nature of our study—and its focus on what we assumed and found to be the early phase of ION diffusion among firms—firm selection was based on reputation for innovativeness. Also, because design development of *semicustom* products requires greater interaction between customers and producers, which may be facilitated by IONs, priority was given to firms producing what are known as application-specific integrated circuits (ASICs). ASICs are a major subset of logic devices and distinct from off-the-shelf products (i.e., microdevices, memory, and linear devices).

In addition, we included semiconductor firms that supported internal or captive, photomask shops to determine whether computer network implementation would be more extensive and the impact of its use different than in firms that contracted with merchant shops alone. Since photomask production and inspection equipment is very expensive, relatively few firms in the industry support captive shops. Of the three semiconductor firms in our sample with captive shops, one used the shop primarily as a laboratory for developing new photomasks processes. The remaining two contracted with merchant shops to handle overflow. Our analysis of the data did not allow us to conclude that network implementation was any more extensive or its impact any different than in firms that contracted with merchant shops.

Interviewees were selected on the basis of their experience and knowledge of data exchanges between customers and vendors and the tasks supported by those exchanges. We were informed of which departments to initially contact through interviews with a few individuals early on in the investigation who had an overview of semiconductor production and contractual relations between firms. Initial interviewees in each firm directed us to the other individuals we subsequently contacted.

Typically, we first interviewed departmental managers and then supervisors and in some cases nonsupervisory personnel as well. In most cases supervisors were directly involved in the tasks that were related to inter-organization exchanges and provided rich descriptions of information requirements. In addition, individuals who were familiar with, or in most cases in charge of, computer networking support were interviewed. Production control managers, circuit design engineers and circuit design tool developers were also interviewed.

Interviews were structured to guide interviewees through descriptions of their responsibilities, departmental tasks, preparation and use of information required to complete tasks, the use of data exchanged with other firms, methods of exchange and current or anticipated use of IONs to support those exchanges. Among other things, this line of inquiry informed us of current and anticipated internal computer networks, as well as ION implementation and use. We also interviewed managers of network facilities and operations.

Each interview was taped and transcribed. The text was then coded by category, following Glaser and Strauss [9]. Sixty-five categories were generated reflecting a variety of activities related to information processing (e.g., internal flow of customer data, scheduling and prioritizing procedures, importing and exporting data, database error correction and detection, division of labor between customer and vendor and so on). Our analyses led us to consider three themes: coordination, integration, and interdependence. While it is beyond the scope of this paper to provide a detailed description of each, they are addressed in the following discussion.

5. COORDINATION: MEDIA SUBSTITUTION AND INTEGRATION

5.1 Interactions Between Customers and Vendors

The interactions described focus on two sets of firms: (1) semiconductor customers and semiconductor producers, and (2) semiconductor producers and photomask shops. Photomask shops, whether merchant or captive, may be viewed as vendors of semiconductor producers. For each set of firms certain interactions pertain to technical specifications exchanged prior to production and another group of interactions after production. Figure 1 depicts the chronological order of these interactions between both sets of firms.

As the schema indicates, data exchanges prior to production are two-way interactions, whereas after production exchanges flow from the vendor side to the producer side. The interactions prior to production between semiconductor customers and producers (1a) involve circuit design development and are thus unique to customers ordering semicustom or custom devices. The remaining exchanges (1b, 2a, 2b) are common to all types of devices.

Semiconductor producers of all devices must produce photomasks. Photomasks are a "hardcopy" of the CAD circuit design; they are glass plates containing geometric design patterns. Photomasks are produced by a sophisticated photolithography technique which currently employs electron beam (E-beam) technology. The exchanges between semiconductor producers and photomask producers (1b) involve transferring data to set up the design database that guide E-beam exposure of the chemically-treated glass plates. Exchanges between the same firms after photomask production (2a) involve the transfer of inspection and quality assurance data to the customer (i.e., the semiconductor manufacturer).

Finally, after the semiconductors are produced through a similar photolithographic process—involving E-beam exposure to a silicon rather than a glass substrate—exchanges involve transferring reliability and quality assurance data to the customer (2b). At any time throughout the process a semiconductor producer may inquire as to the status of its photomask order or a semiconductor customer may inquire as to the status of its order.

Figures 2 through 8 (excluding 6) provide a comparison between pre- and post-ION supported exchanges during: (a) the design phase between ASIC customers and semiconductor producers (Figures 2 and 3), (b) the photomask production phase between semiconductor producers and photomask shops (Figures 4 and 5), and (c) the semiconductor production phase between semiconductor producers and their customers (Figures 7 and 8).

5.2 Coordination and Media Substitution

Each of the post-ION supported exchanges indicated in the figures had been adopted by at least one of the firms in our sample on a routine, experimental

```
Producer Side                   Vendor Side

Interactions Prior to Production:

1a. Semiconductor                    Semiconductor
    Customer         <-------->      Producer

1b. Semiconductor                    Photomask
    Producer         <-------->      Vendor

Interactions After Production:

2a. Semiconductor                    Photomask
    Producer         <-------        Vendor

2b. Semiconductor                    Semiconductor
    Customer         <-------        Producer
```

Fig. 1. Order of interactions between producers and vendors.

or ad hoc basis.[2] Overall, the most extensive implementation of IONs involved applications where their use was characterized as a straightforward substitution for conventional media.

5.2.1 *ASIC Design.* We found that among the six semiconductor firms producing ASIC devices, five used computer networks to transfer design tool software internally to various remote design centers providing support for ASIC customers. However, all six commonly used magnetic tape to transfer design tools to their ASIC customers. (One firm had used computer networks to support design database exchanges with a customer on a one-time basis, Figure 3 at 3.1.)

In most cases the design databases themselves were also transferred via courier from the ASIC customer to the semiconductor firm. However, in a limited number of cases some ASIC customers (i.e., large customers) had negotiated arrangements with producers to exchange design databases and high level simulations results online (Figure 3 at 3.3 and 3.4). In one firm a direct 9600 bps (bits per second) line supported exchanges between customer and producer facilities. The network saves roughly one working day each time a design database must be transferred. Since designs for newer high frequency devices require between five to ten design revisions following each simulation test, on average, IONs save roughly one to two weeks in turn around time.

In one ASIC producing firm, even though design databases are transferred by tape via courier, ASIC customers can run their own simulations remotely,

[2] A summary of the extent of ION adoption in the seven semiconductor firms and five photomask shops, as well as a more detailed description of semiconductor design and production can be obtained by the authors [23].

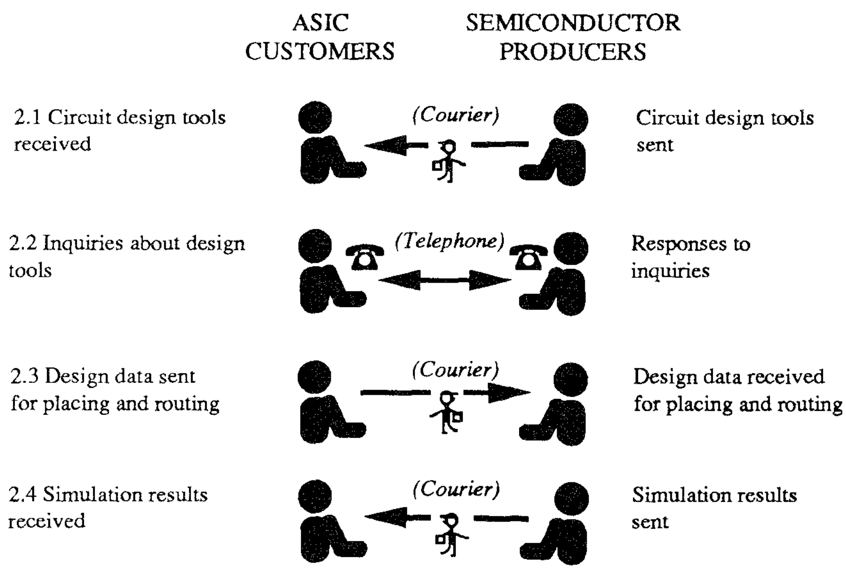

Fig. 2 Pre-ION exchanges between ASIC customers and semiconductor producers during the design process.

using a modem. Because simulations can last as long as 20 hours and more, even this comparatively limited network application significantly reduces the cost of personnel time for the semiconductor producer.

One of the most extensive ION applications supporting design activities among the firms we visited was an electronic mail (E-mail) system that supported communications between 100 ASIC design engineers in one customer firm and 10 application engineers at their semiconductor vendor (see Figure 3, 3.2). The system was used on average every half hour of the working day to respond to design engineer inquiries regarding the semiconductor producer's design tools. Interestingly, the use of E-mail did not substitute for face-to-face meetings. Whereas weekly meetings are useful for addressing high-level issues of interest to many individuals, E-mail is a timely medium for responding to more detailed questions proposed on an individual basis.

In these instances E-mail reduces the costs involved in gathering many individuals to a particular location at a specific time. The fact that face-to-face meetings are still held on a routine basis indicates that the two media serve different but complementary needs by addressing broad and specific design tool inquiries respectively. Although we are clearly unable to generalize, our observations support Rice and Shook's [40] findings that electronic mail substitutes for other media (e.g., phone calls), and Eveland and Bikson's [17] research showing that electronic mail reinforces the use of richer media (e.g., face-to-face meetings). In the firm described above, the outcome of either

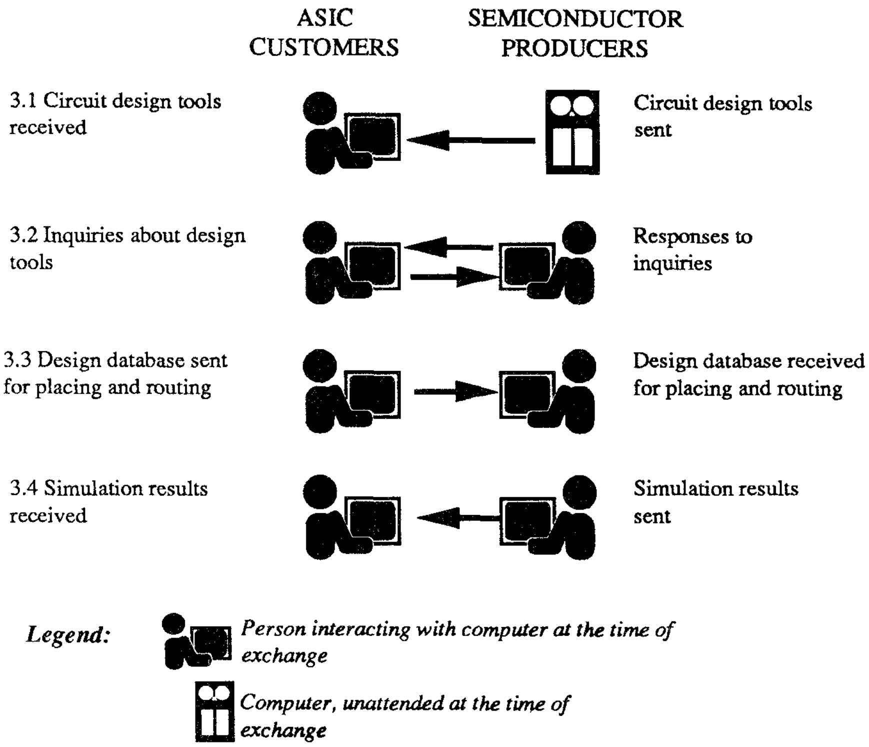

Fig. 3. Post-ION exchanges between ASIC customers and semiconductor producers during the design process.

substitution or reinforcement depends on the specificity of information exchanged.

5.2.2 *Semiconductor Production.* Shifting to photomask production, we found that among the five semiconductor firms that contracted with merchant mask vendors, two used IONs for exchanging design databases (Figure 5 at 5.2). One semiconductor firm also transferred photomask order information online (Figure 5 at 5.1). Figure 6 depicts the chain of tasks required for photomask production.

On average, 10 to 12 mask layers are required to reproduce each integrated circuit design onto a silicon wafer. ION use is particularly effective in saving time when design databases must be physically transported across international boundaries—often resulting in inspection delays at customs offices—or, when portions of a database must be resent to the mask shop because the original database contains errors that need to be corrected by design engineers (Figure 5 at 5.6).

Estimates by individuals in various firms indicate that, on average, three days are required to physically transport a magnetic tape from a design

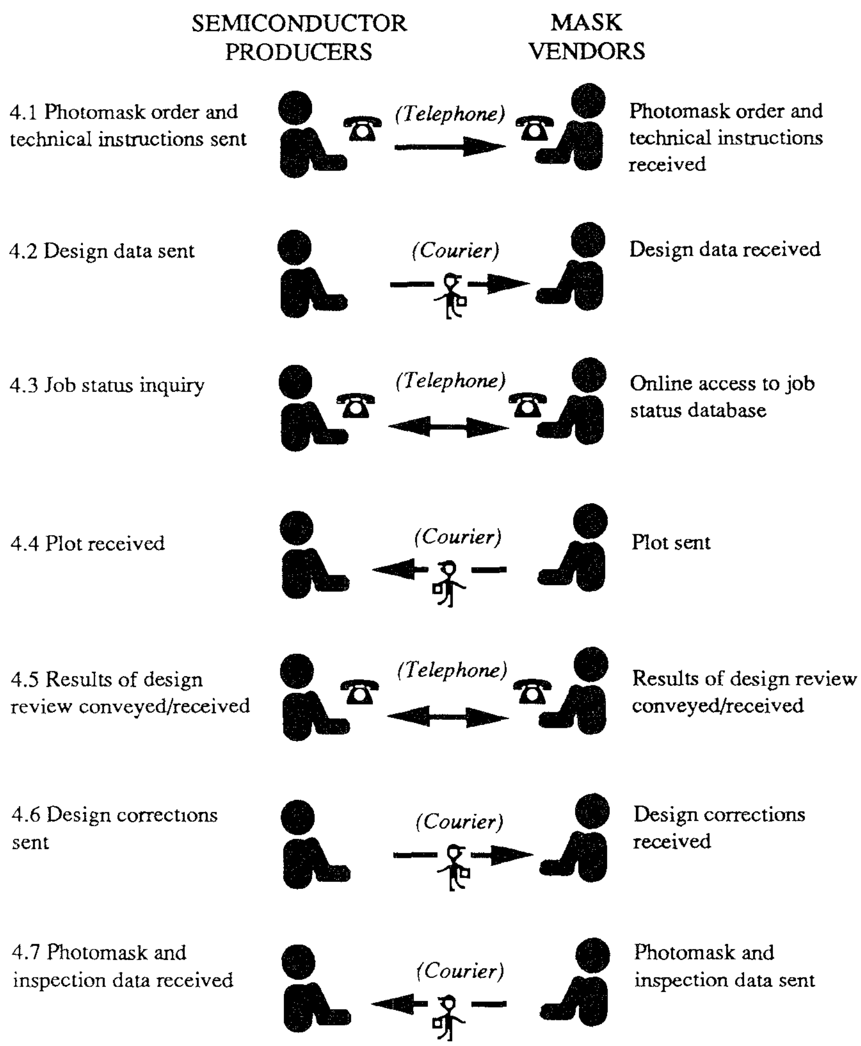

Fig. 4. Pre-ION exchanges between semiconductor producers and mask vendors

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. Failure to meet same day deadlines results in costly delays for mask shops operating on a 24-hour basis.

We found that IONs had been adopted for receiving design database files in three of the five merchant mask shops. (Of the three semiconductor firms with captive mask shops, all used internal networks to transfer design databases.) Their use was limited, but increasing. One merchant shop's use of IONs in 1988 (5126 database file transfers) increased by 133% over the

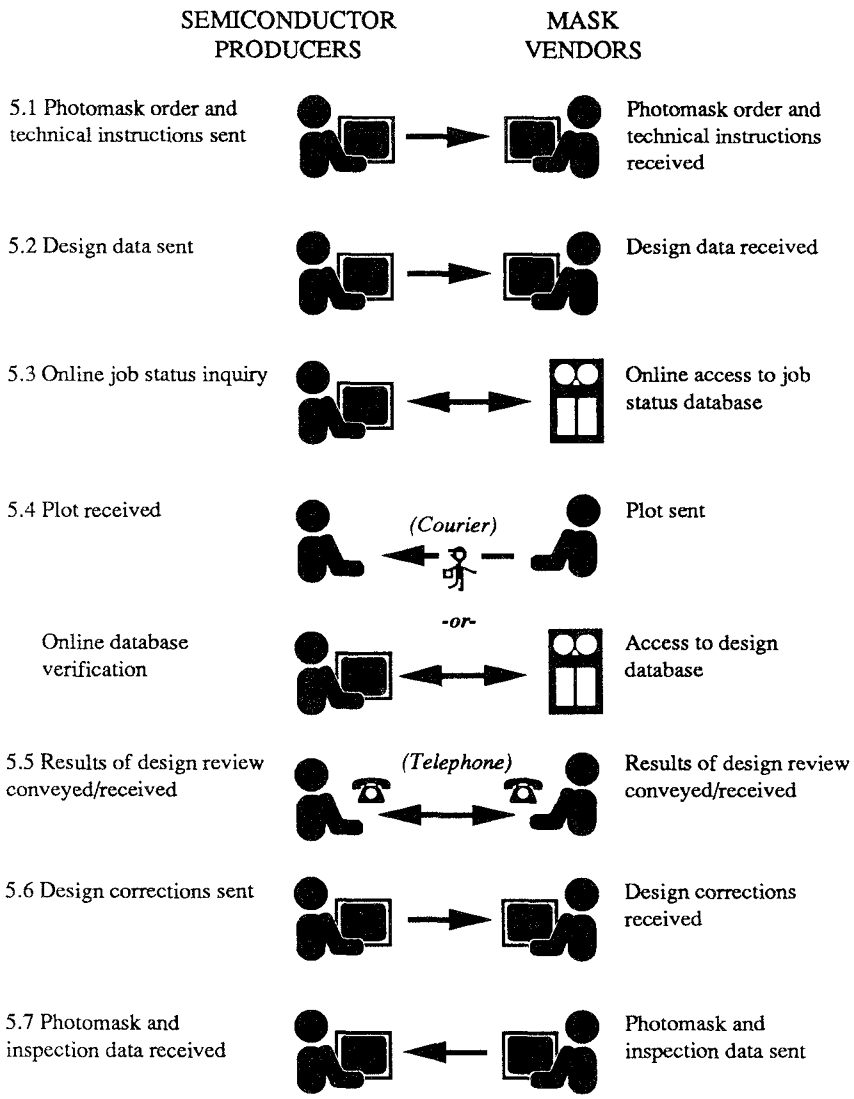

Fig. 5. Post-ION exchanges between semiconductor producers and mask vendors.

previous year. In 1989, usage increased by 43% (7309 database file transfers). Citing an industry slowdown, the firm logged 6861 transfers in 1990.

One merchant photomask shop also uses IONs to improve photomask turn around by supporting online verification checks of design databases (Figure 5 at 5.4). A critical step in the photomask production process involves writing a job deck (i.e., the program that runs the E-beam equipment). The job deck incorporates the technical specifications from the order information supplied by the customer. Only after the job deck has been created is an exact CAD representation of the design available as it will be written by the E-beam. An

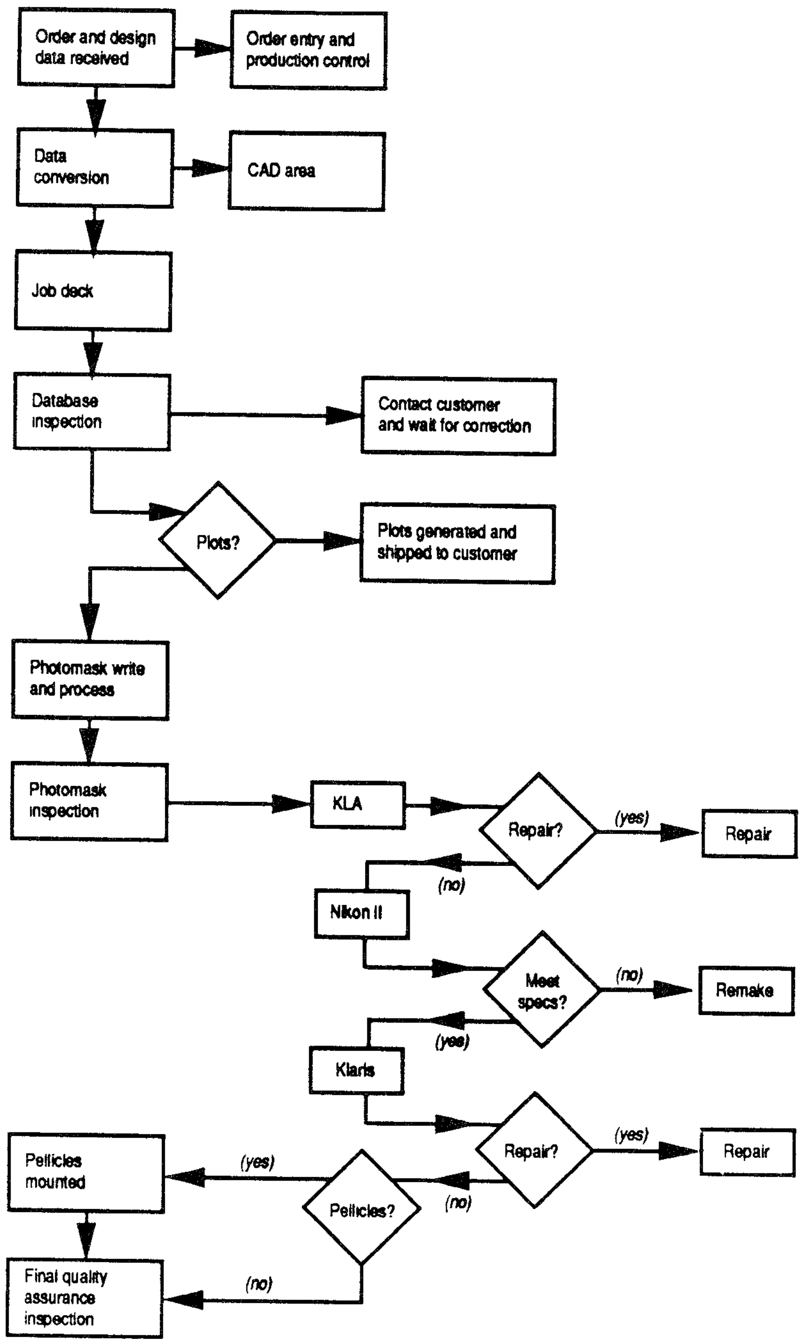

Fig. 6. Chain of tasks required for photomask production.

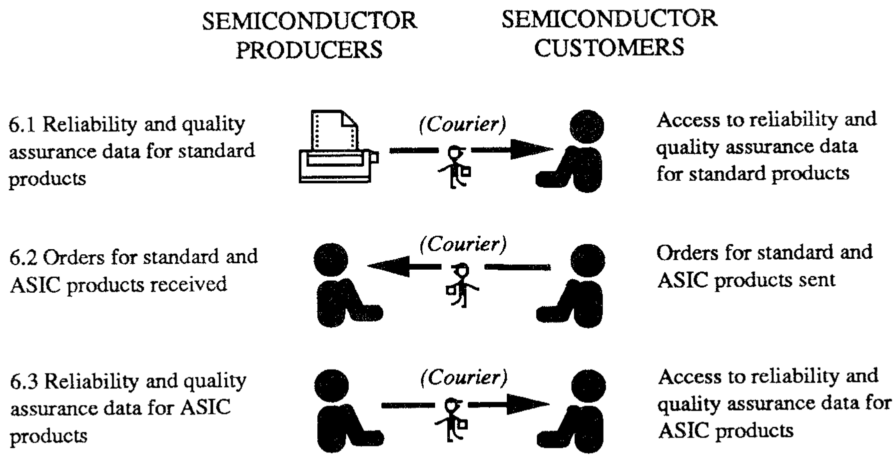

Fig. 7. Pre-ION exchanges between semiconductor producers and semiconductor customers during the manufacturing process.

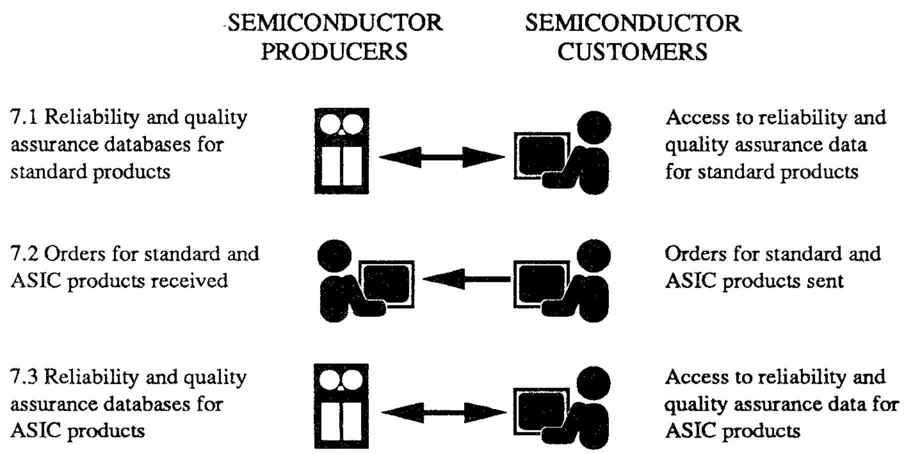

Fig. 8. Post-ION exchanges between semiconductor producers and semiconductor customers during the manufacturing process.

inspection follows, since at this time errors in the design may be discovered. Shop personnel typically contact the semiconductor firm by phone when an error is found (Figure 5 at 5.5). The purpose of the conversation is to determine whether a false error (i.e., an inadvertently caused error of little or no consequence to circuit performance) or a serious error has been discovered. The customer may instruct the technician to correct the error, send a plot of the design, or wait for a corrected database (Figure 5 at 5.6).

The photomask firm that supports online verification telephones the customer after the job deck has been written, and indicates that the design database can be reviewed (Figure 5 at 5.4). Online access allows the customer to visually inspect the design, eliminating verification checks that require the transfer of a plot or film via courier. In some cases online verification eliminates the need for ordering set qualifiers (i.e., an initial set of mask layers delivered to the semiconductor production facility for testing before the complete mask layer set is produced), reducing production time. In the future interactive graphic software and greater bandwidth capacity will allow design engineers in geographically distant locations to revise design databases online, which will have an even greater impact on turn around time.

5.3 Coordination and Integration

The previous section focused on the contribution of ION substitution for improving inter-organization coordination. The following focuses on the importance of intra-organization computing integration for improving inter-organization coordination when IONs are used.

Although IONs improve coordination when they are used as substitutes for other media, their potential for greatest improvement is achieved when they link organizations whose internal computer systems are integrated. Greater internal integration provides the opportunity for greater integration with external units.

5.3.1 *The Role of Intra-Organization Networks for Improved Inter-Organization Coordination.* The following scenario demonstrates how computer integration improves internal coordination, and how information accessible via IONs is contingent on internal integration. The scenario is a composite based on data gathered from the three merchant photomask shops that had undertaken the greatest degree of internal integration.

A *production control system* in a photomask shop that is computerized, and 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 defects, registration and die-to-database comparisons) 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 system* is computer-based and generates a battery of performance data. When the E-beam system is linked to the relational database, performance of the E-beam equipment (e.g., E-beam room temperature and E-beam drift) 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 database systems* provides the capability for correlating size and geometric specifications with yield to predict cost.

Similarly, internal networks in semiconductor firms that support production control, quality assurance and reliability testing, as well as business databases, provide certain benefits reflecting new approaches to organizing internal processes.

The benefits derived from internal computer integration contribute to improving inter-organization coordination. Customers conventionally obtain the status of their orders from photomask shops by telephone from customer service personnel in the vendor firm (Figure 4 at 4.3). The routine necessity to access this information can range from one or more times each day to once over a period of three or four days depending on the product. Online access to photomask shop *production control* information provides customers with greater ability to monitor production flows at the vendor site (Figure 5 at 5.3). This, in turn, improves the customer's ability to manipulate internal production schedules. Online access to production control systems improves inter-organization coordination by reducing the uncertainty about product status tracking.

Access to other information generated by internally integrated computing systems also reduces the uncertainty associated with *product inspection and reliability*. In this context IONs supporting internal integration provide a means for customers to eliminate redundancies in the manufacturing process and thereby improve inter-organization coordination.

When computer-based inspection systems are networked to a relational database in the photomask firm, specific information can be selected and exchanged online between the firm and its customer (Figure 5 at 5.7). Online retrieval of this information from the vendor's databases eliminates the need for capital intensive and time consuming redundant inspections often performed by semiconductor producers.

Similar redundancies can be eliminated for semiconductor customers (Figure 8 at 8.1). When quality assurance and reliability data can be obtained from the semiconductor producer, the qualification cycle for new products at the customer site (which takes from six to nine months or more) can be eliminated.

At the time the interviews were conducted none of the merchant mask vendors was using IONs to exchange inspection data; however, three of the firms were in the process of internally networking their inspection systems. In addition, two of the semiconductor firms were using IONs to transfer quality assurance data to customers for standard products. One system allowed customers access to the producer's internal databases, whereas the other provided access to product information through a third party value-added network.

ION access to vendor production control and reliability information provide certain coordination opportunities for the customer that are contingent on internal integration within the vendor firm. In these instances internal integration is a corequirement of effective ION use.

5.3.2 *The Role of Standards for Improved Inter-Organization Coordination: The Job Deck Example.* As the number of ION partners increases, so does the importance of standardization, given the number of possible combinations of data and permutations of format. If standardization is not achieved, the advantage gained from using IONs to improve the speed of exchange will be mitigated by the need to reprocess information into an organization-specific standard. Because internal computer integration is an important dimension of ION implementation, the need to establish standards between organizations will have an additional impact on internal information processing procedures. Achieving consistency with respect to both internal and external procedures presents a major managerial challenge for successful ION implementation in design and manufacturing environments over the long term.

The following descriptions are two different approaches to establishing procedures for job decks (the software program required to run the E-beam photolithographic equipment in the photomask shop). Variation in job deck creation is not a function of what information is incorporated into the program, but rather how the information is formatted. The first description represents the initiative taken by a third-party vendor and the second represents the initiative of a large, influential semiconductor firm.

At the time the interviews were conducted, one merchant mask vendor had been cooperating with a local entrepreneur to develop a system that would facilitate the exchange of the job deck. The product, a menu driven software package, would complement the hardware and software system currently marketed by the same entrepreneur to facilitate online database transfers. The software would effectively shift the responsibility for writing the job deck from the mask shop to the semiconductor producer. A producer-generated job deck would eliminate the paper-copy transfer of technical instructions required to write the job deck in the photomask shop, reduce the cost of photomask production and turn around time, as well as provide engineers a means to verify designs in-house prior to E-beam write. The entrepreneur's package represents an attempt to create a de facto standard for job deck creation.

The second example involves a semiconductor firm that unilaterally initiated the practice of creating its own job decks in 1985. By mid-1988 an automatic job deck program, developed by the firm, was installed. Design engineers feed technical 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. The automatic job deck allows the firm to program the E-beam equipment to write masks from hierarchical databases thereby alleviating the necessity of 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 contract fewer services with the photomask shop. Photomask vendors, in turn, stand to benefit from the streamlining initiated by the semiconductor firm when they adopt automated order entry systems designed to retrieve relevant order data from the job deck program created by the semiconductor firm. At the time we conducted the interviews, automated order entry systems were not yet implemented in the photomask shops we contacted. Shop personnel retrieved the data from the job deck and reprocessed it into the firm's local standard.

The job deck generation and related developments in the semiconductor firm represent a series of reassessments of information necessary to process design databases prior to transferring them to the photomask shop. These reassessments are examples of how information systems, innovation in themselves, are also the source of additional innovations [38].

One very clear implication of this discussion is that IONs are not as effective if only used as substitutes for conventional media in exchanging information across organization boundaries. Whereas the primary benefits of using IONs as substitutes are related to the speed of exchange, the benefits of using IONs to link integrated computer systems are related to automation, greater control in monitoring and evaluating manufacturing processes and sharing distributed resources.

5.4 Coordination and Reducing Uncertainty

As indicated earlier (Section 2), the model of organizations as information processing systems postulates that improved coordination is the result of a reduction in uncertainty caused by a lack of available information [18]. IONs contribute to reducing production-related uncertainty by making information available more quickly than when conventional media are used. ION-supported transfer of design databases to semiconductor producers and photomask shops, as well as ION-supported access to order status and quality assurance information provide the means to more closely integrate production phases between separate organizational domains.

Production-related uncertainty is at least theoretically distinct from the uncertainty associated with transaction costs (Section 3). Transaction-related uncertainty is the result of the inability to know future contingencies and necessary adaptations required to fulfill contract specifications [50, 51]. To the extent that IONs improve the capability to respond with needed modifications in a timely way, their use reduces transaction costs. IONs cannot reduce transaction related uncertainty in the way they reduce the uncertainty associated with production. Transaction related uncertainty cannot be reduced because the future cannot be known. However, IONs can contribute to decreasing transaction costs by improving the ability of partners to address contingencies when they occur. The use of IONs to transfer new databases to photomask firms when errors have been discovered in the original design is an example of how IONs contribute to reducing transaction-related uncertainty.

6. INTERDEPENDENCE: SHIFTS IN INTER-ORGANIZATION RELATIONS

While the extension of internal integration to external integration improves inter-organizational coordination, ION implementation also affects relationships betwen participating firms. These are a function of the new or different ways in which one organization becomes dependent upon the computing resources or data generated from those resources in another organization as a result of adopting IONs.

6.1 Circuit Design

ASIC circuit designs can be developed by customers in one of two ways. Customers can either purchase workstations and lease design tool software required to construct circuit designs in house or they can use the facilities and support staff at design centers operated by ASIC producers. As a general rule, it is more cost effective for customers to invest in the hardware and software required for in-house circuit design if they intend to order more than two ASIC designs.

As ASIC customers increasingly invest in in-house design facilities, ASIC producers have developed proprietary design tools. These tools specify design parameters determined by fabrication requirements specific to each semiconductor producer and are, therefore, an important interface between design and manufacturing processes. But proprietary tools, in contrast to generic tools—typically marketed by workstation producers—prevent interchangeability of the physical design database. Proprietary tools restrict semiconductor producer selection after the design has been completed. Moreover, design tools comprise libraries of predefined structures. Knowledge of these libraries is associated with a learning curve which means that there are advantages in using the same design tools over time—further restricting customer choice.

On the one hand, ION use facilitates the opportunity to exercise greater customer control over circuit design development (Figure 9 at 1a). On the other hand, the proprietary design tools represent an important strategy employed by semiconductor producers to "lock in" ASIC customers (Figure 9 at 1b).

6.2 Photomask Production

The innovations related to job deck creation by the semiconductor producer (Section 5.3.2) provide certain opportunities for streamlining the internal flow of information within the semiconductor firm and allowing design engineers to verify circuit designs prior to transferring databases to the mask shop (Figure 9 at 4a). But the shift in the division of labor increases the vendor's dependence on the customer. Customer generation of the job deck means that an outside party supplies the software program that will run the core resource in the photomask shop. The vendor becomes dependent on the customer's program to maximize the efficiency of the photolithography equipment (Figure 9 at 4b).

In lieu of customer job deck creation, one photomask vendor allows customers online access to internal databases for verification purposes. On the one hand, this practice may attract customers because it contributes to shortening product turn around time by allowing design engineers to inspect and correct errors more quickly (Figure 9 at 5a). At the same time however, customer access to internal databases raises potential security concerns.

From The Customer's Perspective

Motivations	*Dependence*
1a. Greater control over ASIC design through in-house use of design tool software.	1b. Increased dependence on vendor for providing design-related resources.
2a. More efficient use of scarce resources through more access to detailed scheduling information.	2b. Increased dependence on vendor for providing access to production control information.
3a. Streamlining information flows and eliminating redundant inspections and tests.	3b. Increased dependence on vendor to provide accurate information.

From the Vendor's Perspective

Motivations	*Dependence*
4a. Offload data preparation tasks to customer	4b. Increased dependence on accurate information from customer.
5a. Strategic use to attract and retain customers—access to unique, valued resources.	5b. Increased vulnerability of accessible proprietary resources and customer data.
6a. Reduced personnel cost in providing timely status information to customer.	6b. Increased accountability for internal production scheduling.

Fig. 9. Motivations and corresponding sources of change in interdependence between firms exchanging information over inter-organization computer networks.

Vendors are more vulnerable when proprietary resources are potentially accessible to outside parties (Figure 9 at 5b). This vulnerability may lead vendors to develop arrangements that make it more difficult for outside parties to access vendor databases, restricting the degree of network use. Or, they may allow only select customers (i.e., customers that place large orders) access to their systems.

6.3 Production Control

While online access to vendor production control systems would improve the customer's ability to control internal scheduling (Figure 9 at 2a), acquisition of information would be contingent on accessing privileges from the vendor. Over a relatively short period of time the customer's improved ability to schedule scarce resources would become routine thereby reflecting an increase in dependence on the vendor (Figure 9 at 2b).

A different shift in interdependence is associated with vulnerability on the vendor side. While online access to production control systems would provide order status to customers without cost to the vendor's customer service personnel (Figure 9 at 6a), it may increase vendor accountability.

We found positive interest among semiconductor producers for using IONs to access photomask production control systems. However, we also found nearly uniform resistance on the part of the four merchant photomask vendors with computer-supported production control systems to allow their customers access. Moreover, each of the semiconductor firms was hesitant to allow their customers access to their production control systems.

Vendor reluctance stems from the fear that customers will become more involved in their production processes. The fear is based on the perception that customers do not understand vendor production processes well enough to interpret changes in prioritizing and scheduling. If customers observe that their orders have been located in a particular production area for an inordinate amount of time or that the priority of their orders have been downgraded, vendors may be required to explain unexpected shifts in order status (Figure 9 at 6b). Vendors also face the risk of one customer gaining access to another customer's data. This increases the vendor's vulnerability in terms of trust and even liability.

6.4 Inspection and Reliability Data

Online retrieval of data generated by computer-supported inspection and testing systems can result in significant contributions to productivity by eliminating the need to perform redundant inspections and tests by customer firms. This contributes to shortening turn around time (Figure 9 at 3a).

At the same time, access to this data represents a series of new dependencies for customers who no longer rely on information generated under their direct supervision (Figure 9 at 3b). Accuracy of the information obtained from the vendor affects the quality of the product manufactured by the customer.

6.5 Computing Resources

Each of these motivations, along with the incentive to transfer design databases more quickly over geographically distant locations, creates or increases dependence on the computing resources of participating organizations. We anticipate that the direction of dependence developed by ION adoption will reflect existing relationships between firms.

But there is a tradeoff between the number of online partners an organization can accommodate and system load performance. Computing system capacity must match the requirement to handle the largest possible number of partners at acceptable performance levels. If the performance level is just acceptable, then additional partners cannot be served without jeopardizing response time. If additional partners are desirable, then the system must be upgraded. Expenditures in computing equipment are asset investments that represent an increase in transaction costs for the vendor providing ION support to establish or maintain customer contracts.

It appears that initially vendors will accommodate as many customers as possible and bear the cost of computing upgrades as a cost of doing business. However, it is also assumed that the resources to support upgrades are limited. The vendor must tradeoff supporting a larger number of customers and investment in the facilities required to maintain adequate performance.

6.6 Interdependence as Cost

The shifts in interdependence we have described are a function of how partners choose to use IONs to exchange information. The changes are directly related to, but not solely determined by, the technical attributes of IONs described earlier in Section 2. As Estrin [15] has argued, these attributes affect certain changes in communication patterns.

The shifts in interdependence described represent changes in communication patterns associated with penetration (i.e., direct access to another firm's computing and information resources) and segmentation (nonuniversal access to these resources). Each of the six dyads in Figure 9 are linked to shifts in communication patterns associated with either penetration (2ab, 3ab, 4ab, 5ab, 6ab) or segmentation (1ab).

The segmentation dyad represents the investment that an ASIC customer makes in using proprietary design tools. From the customer's perspective, use of tools that restrict interchangeability increases the specificity of physical and human assets. The customer is "locked in" to a particular semiconductor producer by the investment in the tools themselves and the significant learning curve associated with using the software.

The remaining dyads that characterize interdependence are associated with penetration. The costs involved are the vulnerabilities based on the use of computing resources and information generated by those resources outside the parameters of a firm's conventional boundaries. Following the transaction cost perspective [50, 51] these are vulnerability costs [29, 30] associated with creating and maintaining contracts.

These shifts in interdependence between firms adopting IONs reinforce our own conviction that the use of IONs ought to be viewed differently than the use and impact of other media.

It is important to note that the intensification of the interdependence between separate firms emerges within the framework of contractual relationships. Thus, corporate realignment based on ION adoption that results in shifts in organizational relationship falls outside of mechanisms conventionally associated with greater interfirm interdependence, such as joint ventures or mergers.

7. THE VALUE CHAIN

The organization "value chain" provides a useful tool for overseeing several dimensions of the use and impact of IONs in our study. As described by Porter [37, also 11, 38, 41] the value chain represents a series of generic activities that can be divided into more discrete activities. Figure 10 depicts the five generic categories in Porter's model: inbound logistics, operations, outbound logistics, marketing and sales, and service [37, pp. 44–48]. The activities examined in our study fall within the first three broad categories.

Each category also represents a system of activities that are interdependent with activities in other categories. For example, in our study the tasks

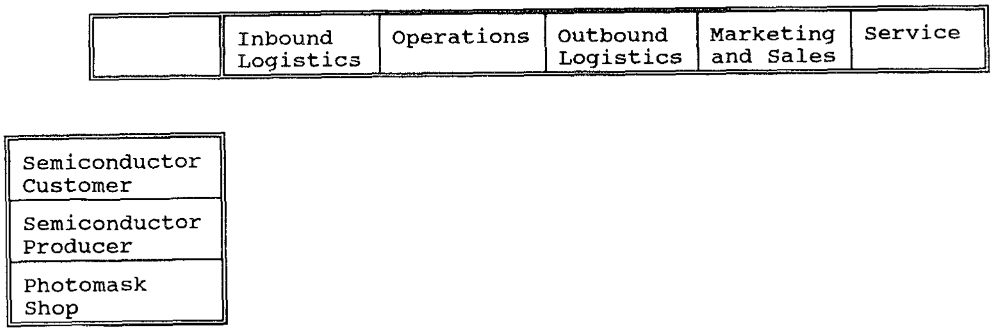

Fig 10. Porter's value chain: Primary activities

involved in collecting technical specifications about semiconductor design (inbound logistics) are directly related to the performance of tasks involving semiconductor production (operations), and product reliability data generated during production (operations) are related to the information the customer receives when the semiconductor product is delivered (outbound logistics).

Similarly, each category represents a system of activities that are interdependent with the activities in other firms. Porter refers to these as "vertical linkages" [37, pp. 50–53]. These linkages are based on the exchanges between customers and suppliers described earlier (see Figure 1). Each set of exchanges between a customer-vendor dyad supports a system of discrete activities that comprise the broader category of activity in the respective firm. For example, the ASIC design activity in the customer firm (operations) corresponds to the design engineer and computer resource support provided by the semiconductor vendor firm (inbound logistics). The intersection of tasks characterize the interdependence between firms.

In our study, the activities of the respective firms have been defined by the exchanges supported by IONs. This follows Porter's recommendation that "product flow, order flow or paper flow" [37, p. 45] can be useful in determining the subdivisions of broad functions. In our investigation we focused on interorganization data-related exchanges that could be supported by IONs. These exchanges, given in Figure 11, represent subdivisions or discrete activities that comprise broader complementary systems of activities within respective firms.

Also indicated in Figure 11 are the primary benefits and adoption constraints associated with ION adoption. The benefits are related to improved coordination which is the result of the improved speed with which information is exchanged, the availability of information previously not accessible that has a direct bearing on cost, or, in one instance, greater control over design activities.

The adoption constraints include limited bandwidth capacity of public networks, permission to access internal databases and investment in internal computer integration. Some exchanges are not associated with significant constraints beyond the basic lack of experience or expense (e.g., E-Mail used

Process	Exchanges	ION Capacity	Primary Benefits	Adoption Constraints
ASIC Design	Design Tool Exchange	File-Transfer	Internal Control	Bandwidth
	Design Tool Inquiries	E-Mail	Timely Response	*
	Design Data Transfer	File-Transfer	Time Reduction	Bandwidth
	Simulation Tests Run	Remote Login	Time Reduction	Permission
	Results Received	File-Transfer	Time Reduction	*
Photomask Production	Order and Instructions	File-Transfer	Time Reduction	Integration
	Design Data Sent	File-Transfer	Time Reduction	Bandwidth/ Integration
	Job Status Inquiries	Remote Login	Internal Control	Permission/ Integration
	Design Verification	Remote Login	Time/Cost Reduction	Permission
	Design Correction	File-Transfer	Time Reduction	Bandwidth/ Integration
	Inspection Data	File Transfer	Time/Cost Reduction	Bandwidth/ Integration
Chip Production	Reliability Data for Standardized Products	Remote Login	Time/Cost Reduction	Bandwidth/ Integration
	Order Entry	File Transfer	Time Reduction	Integration
	Reliability Data for ASIC Products	File Transfer	Time/Cost Reduction	Bandwidth/ Integration

* No significant constraint.

Fig. 11. ION-supported primary activities in the semiconductor industry.

to respond to design tool inquiries). Coordination benefits obtained by ION adoption are contingent on overcoming adoption constraints.Overcoming these constraints is not necessarily inevitable. Permission to access internal databases and investment in computer integration are a function of management strategy, resource allocation and trust between firms. To the extent that coordination benefits are contingent on these management- and organization-specific decisions, the long-term impact of IONs will be a consequence of the integration decision-makers elect to implement.

8. CONCLUSION

The purpose of our study was to understand how IONs are being used in the semiconductor industry to support inter-organization coordination. Among the innovative semiconductor firms and five merchant mask shops in which we conducted eighty-two interviews, IONs are being used primarily as substitutes for conventional media. In this capacity, the most visible benefits are associated with the speed of transferring design databases, thereby contributing to reduced product turnaround time.

More dramatic improvements in coordination, however, are evident and anticipated as firms integrate their internal computing systems. In this capacity, ION benefits are related to automation, greater control in monitoring and evaluating manufacturing processes, and sharing distributed resources. The process of internal computer integration, however, is difficult because it requires that firms reassess their information processing requirements. Moreover, computer integration as a corequirement of effective ION implementation implies that information content and format must be consistent among participating organizations.

Finally, for each of the opportunities that motivate firms to adopt IONs, there are corresponding vulnerabilities that result in shifts in interdependence. These shifts involve new dependencies on computing resources and information generated on those resources outside the boundaries of an organization's conventional domain of control. These represent additional transaction costs (i.e., costs associated with establishing and maintaining contracts) which may offset the reduction of other transaction and production costs associated with ION use.

The issues addressed in this research are of theoretical interest to scholars of information technologies, as well as practical interest to managers who must oversee the implementation of computer networks that are of increasing importance in the marketplace.

ACKNOWLEDGMENTS

The authors would like to thank the individuals we interviewed. We are also grateful to Leigh Starr, Ron Rice, Carol Saunders and the anonymous reviewers for their helpful recommendations, and to Fred Fortune (San Jose, Calif.) and Edna White and Fritz Postlethwaite (Boca Raton, Fla.) for their assistance in developing the graphics that appear in this article.

REFERENCES

1. ADLER, P. S. New technologies, new skills. *California Manage Rev 29* (1986), 9–28.
2. ADLER, P. S. CAD/CAM: Managerial Challenges and Research Issues. *IEEE Trans Engineer. Manage. 36* (1989), 202–215
3. BAKOS, J. Y. Interorganizational Information Systems in Vertical Markets, In *Proceedings of the 24th Annual Hawaii International Conference on System Sciences* (1991), 241–250
4. BARRETT, S., AND KONSYNSKI, B. Inter-organization information sharing systems. *Manage. Inf. Syst. Q. 6* (1982), 93–105.
5. BENJAMIN, R I., ROCKART, J. F , MORTON, M. S. S., AND WYMAN, J. Information technology: A strategic opportunity *Sloan Manage Rev. 25*, 3 (1984), 3–10.

6. BENJAMIN, R. I., DELONG, D. W., AND MORTON, M. S. S. The realities of electronic data interchange: How much competitive advantage? M.I.T. Management of the 1990s, CISR WP #166, 1988.
7 BODENSTEINER, W. D. Information channel utilization varying research and development project conditions: An aspect of inter-organizational communication channel usages. Unpublished doctoral dissertation, The Univ. of Texas, Austin, 1970.
8. CASH, J. I. Inter-organizational systems: An information society opportunity or threat? *Inf. Soc. 3*, (1985), 199–228.
9. CASH, J. I., AND KONSYNSKI, B. R. IS redraws competitive boundaries. *Harvard Bus. Rev.* (March-April, 1985), 134–142.
10. CIBORRA, C. U. Reframing the role of computers in organizations—The transaction costs approach. *Off. Technol. People. 3* (1987), 17–38.
11. CLEMONS, E. K., AND MCFARLAN, F. W. Telecom: Hook up or lose out. *Harvard Bus. Rev* (July-Aug., 1986), 90–97.
12. CLEMONS, E. K., AND ROW, M. McKesson drug company: A case study of Economist—A strategic information system. *J. Manage. Inf. Syst 5* (1988), 36–50
13. DAFT, R. L., AND LENGEL, R. H. Information richness: A new approach to managerial behavior and organization design. In *Research in Organizational Behavior*, Vol. 6, B. M. Staw and L. L. Cummings, Eds. JAI Press, Greenwich, Conn., 1984, 191–233.
14. DAFT, R. L., AND LENGEL, R. H. Organizatoinal information requirements, media richness and structural design. *Manage. Sci. 32* (1986), 554–571.
15. ESTRIN, D. Interconnection of private networks. *Telecommun. Policy* (Sept., 1987), 247–258.
16. ESTRIN, D., AND HART, P. Inter-organization computer networks in the design and manufacturing of semiconductors: Final report of a two year study. TR-89-13: Computer Science Dept., Univ. of Southern California, Los Angeles, 1989.
17. EVELAND, J. D., AND BIKSON, T. K. Work group structures and computer support: A field experiment. *ACM Trans. Off. Inf. Syst. 6* (1988), 354–379.
18 GALBRAITH, J. R. *Organization Design*. Addison-Wesley, Reading, Mass., 1977.
19. GLASER, B. G., AND STRAUSS, A. L. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine de Gruyter, New York, 1967.
20. HART, P., AND ESTRIN, D. Inter-organization networks in support of application-specific integrated circuits: An empirical study. In *Proceedings of the International Telecommunications Society* (Venice, Italy, Mar. 18–21, 1990).
21. HART, P., AND ESTRIN, D. Inter-organization computer networks: Indications of shifts in interdependence. *SIGOIS Bull. 11* (1990), 79–88.
22. HART, P., AND ESTRIN, D. Computer integration: A co-requirement for effective inter-organization computer network implementation. In *Proceedings of the Conference on Computer-Supported Cooperative Work* (Los Angeles, Calif., Oct. 7–10, 1990), 131–142.
23. HART, P. AND ESTRIN, D. Inter-Organization Networks, Computer Integration, and Shifts in Interdependence: The Case of the Semiconductor Industry. TR-91-13: Computer Science Dept., Univ. of Southern California, Los Angeles, 1991.
24. HOLLAND, W. E., STEAD, B. A., AND LEIBROCK, R. C. Information channel/source selection as a correlate of technical uncertainty in a research and development organization. *IEEE Trans. Eng. Manage. 23* (1976), 163–167.
25. JOHNSTON, H. R., AND VITALE, M. R. Creating competitive advantage with interorganizational information systems. *MIS Q.* (June, 1988), 153–165.
26. KAUFMAN, F. Data systems that cross company boundaries. *Harvard Bus. Rev.* (Jan.-Feb., 1966), 141–155.
27. KAVAN, B. C., AND VAN OVER, D. Electronic data interchange: A research agenda. In *Proceedings of HICSS* (1990), 192–198.
28. KEEN, P. G. W. *Competing in Time*. Ballinger, Cambridge, Mass., 1986.
29. MALONE, T. W. Modeling coordination in organizations and markets. *Manage. Sci. 33* (1987), 1317–1332.
30. MALONE, T. W., AND SMITH, S. A. Modeling the performance or organizational structures. *Oper. Res. 36* (1988), 421–436.

31. MALONE, T. W., YATES, J., AND BENJAMIN, R. I. Electronic markets and electronic hierarchies *Commun. ACM. 30* (1987), 484–497.
32 MALONE, T W., YATES, J, AND BENJAMIN, R. I The logic of electronic markets *Harvard Bus. Rev* (May-June, 1989), 166–170.
33. MEIER, J., AND CHISMAR, W. G. A formal model of the introduction of a vertical EDI system. In *Proceedings of HICSS* (1991), 508–523
34 MEYER, N. D AND BOONE, M E *The Information Edge* McGraw-Hill, New York, 1987
35 NIDUMOLU, S. R The impact of interorganizational systems on the form and climate of seller-buyer relationships: A structural equations modelling approach. In *Proceedings of the 10th International Conference on Information Systems* (1989), 289–304
36. PONTING, B EDI's next frontier: Sending designs and graphics along with the forms. *Data Commun.* (May, 1988), 55–60
37 PORTER, M. E. *Competitive Advantage.* The Free Press, New York, 1985.
38. PORTER, M E., AND MILLAR, V. E How information gives you competitive advantage *Harvard Bus Rev.* (July-Aug., 1985), 149–160.
39. RICE, R. E Computer-mediated communication and organizational innovation *J Commun 37*, 4 (1987), 65–94.
40. RICE, R. E AND SHOOK, D E Access to, usage of, and outcomes from an electronic messaging system. *ACM Trans. Off. Inf. Syst. 6* (1988), 255–276
41. ROCKART, J. F, AND SHORT, J. E. IT in the 1990s: Managing organizational interdependence. *Sloan Manage. Rev. 30*, 2 (1989), 7–17
42 SAUNDERS, C S, AND CLARK, S. The impact of interorganizational power on EDI adoption. Presented at the *24th International Conference on Social Systems* (1991)
43. SCOTT, W R Technology and structure: An organizational-level perspective. In *Technology and Organizations*, P S Goodman, L S. Sproull, and Associates Jossey-Bass, San Francisco, 1990, 109–143.
44. SHORT, J, WILLIAMS, E, AND CHRISTIE, B *The Social Psychology of Telecommunications.* Wiley, New York, 1976.
45. STRASSMANN, P. A. *Information Payoff* The Free Press, New York, 1985
46 THOMPSON, J. *Organizations in Action.* McGraw-Hill, Chicago, 1967
47. TUSHMAN, M. L., AND NADLER, D. A Information processing as an integrating concept in organizational design. *Academy Manage Rev. 3* (1978), 613–624
48 VENKATRAMAN, N., AND ZAHEER, A. Electronic integration and strategic advantage: A quasi-experimental study in the insurance industry. *Inf Syst. Res. 1* (1990), 377–393
49. WEY, Y. J., AND GIBSON, D V Influence of the external environment on interorganizational systems: An integration of transaction costs and resource dependence perspectives. In *Proceedings of HICSS* (1991), 501–507.
50. WILLIAMSON, O. *Markets and Hierarchies: Analysis and Antitrust Implications.* The Free Press, New York, 1975
51 WILLIAMSON, O. *The Economic Institutions of Capitalism.* The Free Press, New York, 1985.
52. WISEMAN, C *Strategic Information Systems.* Irwin, Homewood, Ill., 1988