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ELECTRONICALLY-MEDIATED PARTNERSHIPS: THE USE OF CAD TECHNOLOGIES IN SUPPLIER RELATIONS

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Abstract

We explore the conditions under which industrial buyers use computer-aided design (CAD) technology to coordinate design activities with some suppliers and not others. We hypothesize greater use of the technology in relationships where it offers "production costs" benefits—when features of the codesign task demand tighter coordination between engineers. Electronic coordination, however, is a source of vulnerability in the relationship. Boundary permeability increases as suppliers can electronically access strategic information and knowledge in ways the buyer cannot control. The effective use of CAD technologies requires investments in human and social capital, typically specific to a supplier. We therefore hypothesize lesser use of the technology in relationships where it presents "transaction costs" risks, unless safeguards are implemented.

We then examine the performance implications of these investments. We hypothesize a positive effect of technology on the satisfaction with coordination performance, but more importantly we anticipate an interaction effect between technology and task characteristics.

We test our hypotheses using original data from a sample of 194 relationships involving all automakers in the U.S. and Japan. The results strongly support most hypotheses, in particular our prediction of an interaction effect of task variables. We find that the impact of CAD use on satisfaction with interfirm coordination varies in a non-monotonic way with the level of analyzability and routineness of the codesign task. Theoretical implications for the literature on the impact of IT on organizations and interorganizational relations in general are discussed, as are some practical implications and limitations of the study.

Keywords: CAD (computer aided design), interorganizational relations, buyer-supplier relations, contingency theory, interaction effects

1. INTRODUCTION

In their search for shorter lead-time, lower costs, and better quality, industrial buyers around the globe have moved away from vertical integration on the one hand and arm's-length supply relations on the other, developing cooperative arrangements. To support these arrangements, manufacturers are intensifying their use of information technology (IT). Earlier, electronic data interchange (EDI) applications were implemented for structured tasks such as logistics or "just-in-time" delivery; now, manufacturers also use IT to support the coordination of non-algorithmic, complex, and creative tasks such as codesign.

We explore the emerging "partnership-mediating" role of information technology. In the context of component design engineering between automobile-industry buyers and suppliers, we empirically examined the antecedents and performance implications of using computer-aided design (CAD) technologies across firm boundaries. Using original questionnaire and interview data from

an extensive study of 194 relationships in both the U.S. and Japan, we examine features of the component and the upstream market as motives for automakers to invest in using CAD. Finally, we test whether and when the use of the technology systematically translates into better coordination.

2. THE USE OF CAD TECHNOLOGIES IN SUPPLIER PARTNERSHIPS

The Design Engineering Task. Design, especially of a new car model, is a large, complex, ill-defined, and unstructured activity requiring close communication between hundreds of engineers. We focus on the design engineering phase, where design specifications are translated into detailed drawings and/or design data files, which become the basis of communication between the buyer and suppliers. Engineers balance various interdependent factors, such as price, weight, performance, producability, and interactions with surrounding parts—optimizing some and meeting standards with all. "Design parameters depend on one another, often in very complex and convoluted ways. This is turn constrains the way designers go about their tasks" (Baldwin and Clark forthcoming). Communication, coordination, and conflict resolution become as important as engineering.

CAD technologies. Since the early 1960s, the use of CAD tools has resulted in better quality products, lower costs, and faster development (Majchrzak and Salzman 1989; Salzman 1989). CAD systems achieve greater accuracy and save redrawing time. Some automakers encode their internal design and drafting rules into software systems and provide suppliers access.

To capture the large variance in CAD use, we have developed a spectrum variable. Buying-company design engineers were asked to report whether each of eight key CAD functionalities were effectively used in a given relationship (see appendix for measurement scales). Greater values of the index reflect more extensive use of CAD technology.

The Interorganizational Level of Analysis. CAD tools are used between firms when buyers decide neither to develop and produce a component internally, nor to directly procure it from a spot market, but rather to obtain the component from within a close supplier relationship—an interesting intermediate solution.

However, using CAD technology between companies also creates problems. It provides each firm greater access to information generated and stored by the other—a source of vulnerability. In addition, using CAD effectively requires significant supplier-specific human investments, which increase the cost of exiting the relationship—a so-called "transaction cost."

Physical capital is investments in equipment used to add value to the product or to develop it more efficiently. Managers we met understood the cost and value of this sort of capital and usually had measures to assess and justify the expense. Part of this investment is general-purpose software and hardware, but part may be highly specific to a given supplier—integrating protocols, for example.

Human capital represents the investments in engineers' skills and knowledge. Managers are usually willing to pay some costs of developing this kind of capital—releasing their engineers to attend joint technical programs, for instance—even though they can hardly quantify its return value. Part of this investment is transferable, but part is highly idiosyncratic to the component, the supplier, or both.

Social capital resides in personal relationships: the obligations and expectations, the information-flow capability of the social structure, and norms accompanied by sanctions (Coleman 1988). Managers understand that their engineers' ability to work with their supplier counterparts is valuable and worth developing. By definition, social capital is idiosyncratic to a relationship.

3. PRODUCTION COSTS BENEFITS

"Production costs" benefits primarily stem from CAD's ability to increase the information processing and exchange capabilities of the relationship. At its most basic level, CAD systems automate drafting tasks and speed the production of new drawings after modifications, decreasing the time and cost of design change iterations. In addition, CAD's detailed representations increase the

quality of the information exchanged, helping engineers better understand each others' designs. Advanced three-dimensional systems provide greater benefits, although engineers agree designing in 3D is more difficult and time consuming.

At another level, CAD operates as an informating technology (Zuboff 1988). The analysis features allow for better simulation and testing of designs. For example, a team of engineers built an axle and suspension system on CAD, then simulated the performance of an actual axle traveling over a rough road. The results corresponded to test track results and helped identify parts most likely to fail. "The ability to conduct more diverse experiments with novel technical possibilities and to learn more effectively than with alternative methods can lead to better R&D output" (Thomke 1998, p. 55). The same benefits apply across firm boundaries.

Finally, CAD systems support communication. When teams of engineers explain their designs to each other or resolve conflicts, they often discuss in front of a CAD terminal. Also, some manufacturers provide suppliers with access to their central CAD files or standard parts libraries. Supplier engineers can independently ensure that their designs fit with the project or check the specifications of standard fasteners.

When do buyers choose to leverage these coordination enhancing capabilities offered by current CAD technology? When do they invest in implementing CAD exchange with a supplier? To answer this question, we extend the information-processing view of organizational design to the interorganizational level of analysis and use it as an integrative framework. We build from Galbraith's thesis that the information-processing capabilities of an organization should be matched with its information-processing needs (Galbraith 1977; Daft and Lengel 1986; Daft and McIntosh 1981; Tushman 1978, 1979; Tushman and Nadler 1978). Specifically, we argue that the information processing needs of a codesign relationship are due to uncertainty and complexity and that the information processing capabilities of the relationship are enhanced by the use of CAD tools. In the automobile context, this tends to occur under (1) higher levels of product customization (complexity), (2) higher levels of supplier involvement in design (complexity), and (3) higher frequency of design changes (uncertainty). These relationships are elaborated in sections below.

A car is a complex "set of components that together provide utility to users. System performance is dependent not only upon constituent components, but also on the extent to which they are compatible with each other" (Garud and Kumaraswami 1993, p. 353). Car components, in contrast to computers, are highly interdependent and customized to each model. Component interdependencies require design parameter interdependence, which in turn requires complex coordination at each supplier interface (Sanchez and Mahoney 1996; Ulrich 1995).

We distinguish between car components according to their local modularity. Modular components (e.g., batteries, tires) have few interdependencies with other portions of the car, so they can be designed separately, in parallel. Low modularity components (e.g., suspension or braking systems) are highly interdependent with the rest of the vehicle, requiring more interactive problem-solving sequences and more cross-component cycling, hence greater requirements for information exchange.

Level of product customization. As a result of the architectural design of the car, a buyer may choose to customize a component or use standardized parts. Customizing a component implies maintaining some parameter interdependency. A customized component (e.g., a car seat) involves a greater number of interdependencies with the design parameters of other units of the car (e.g., body frame and color, interior design), which in turn requires tight coordination and testing over a greater number of design interfaces. In contrast, for a standardized component, design and development tasks can be defined, structured, and separated from each other according to clearly prespecified interfaces and testing protocols. CAD tools, used as an electronic drafting board and a communication tool, contribute to speed up and reduce the cost of the iterative and cyclical problem-solving and conflict resolution processes that naturally arise around the interdependent design parameters. As a simulation tool, it can also reduce the cost of experimenting and testing different technical solutions for enhanced customization. We thus propose (see Figure 1 for a summary of the model):

> *Hypothesis H1:* Automakers make more extensive use of CAD technologies with suppliers for components with a higher level of customization to the final vehicle.

Frequency of Design Changes. Product development is a dynamic process. Design requirements and component specifications change multiple times during the course of the design process. While some components remain stable throughout the development process, others undergo multiple adaptations and redesigns. Even though each design decision is made in light of previous decisions, it is still subject to change based on later results in the process. A manufacturing analysis at the supplier may find that
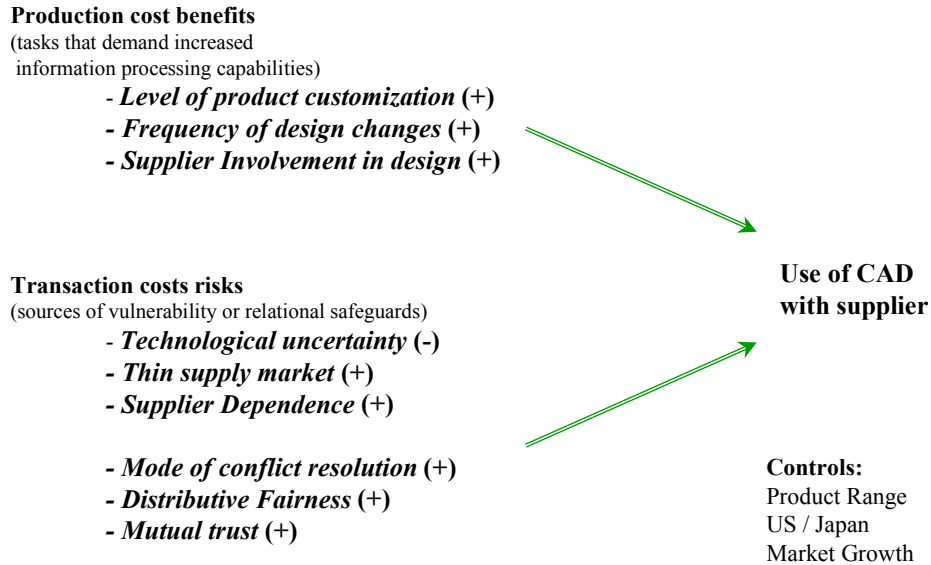
Production cost benefits
(tasks that demand increased
 information processing capabilities)
     - *Level of product customization* (+)
     - *Frequency of design changes* (+)
     - *Supplier Involvement in design* (+)

**Use of CAD
with supplier**

Transaction costs risks
(sources of vulnerability or relational safeguards)
     - *Technological uncertainty* (-)
     - *Thin supply market* (+)
     - *Supplier Dependence* (+)

     - *Mode of conflict resolution* (+)
     - *Distributive Fairness* (+)
     - *Mutual trust* (+)

Controls:
Product Range
US / Japan
Market Growth

Figure 1. Antecedents of CAD Use

some previous decision is unworkable and would need reconsideration. As Clark and Fujimoto (1991) document, engineering changes are the rule rather than the exception and constitute a major cost driver, in particular those changes made to parts or drawings that have already been released. Design changes also become extremely costly when made late in the development process, especially after process design or tooling have started (Schrader and Gopfert 1996).

Design changes cause iterations, i.e., the repetition of design tasks due to the arrival or discovery of new information (Smith and Eppinger 1997). There are two ways to accelerate the design process in response to frequent design changes: (1) to execute faster iterations or (2) to conduct fewer iterations. Researchers have recently developed several models of iteration that may provide an initial ordering of tasks that minimizes the expected development time (Ha and Porteus 1995; Krishnan, Eppinger and Whitney 1997; Steward 1981). The other alternative recognizes that the use of information technology and engineering models helps achieve faster iterations. Engineers at one company can electronically extract up-dated versions of the design, make changes to it, and transfer it back with the push of a button, without ever having to draft it on paper. This reasoning leads to the following hypothesis:

> **Hypothesis H2:** Automakers make more extensive use of CAD technologies with suppliers for components requiring more frequent design changes.

Supplier Involvement in Design. The level of task interdependence between buyer and supplier engineers is also the result of managerial decisions as how to partition the various tasks between the two teams. Significant reductions in development time have been attributed to greater supplier involvement (Asanuma 1989; Clark 1989; Clark and Fujimoto 1991; Cusumano and Takeishi 1991; Funk 1993). A supplier's early involvement and greater responsibility reduce the number of supplier activities that need to be delayed and make possible parallel design. Suppliers can begin designing their tooling and testing protocols early in the process, thereby reducing the number of supplier related design changes and delays. King and Penlesky (1992) found that tooling production for molded or stamped components is often the source of product development delays. Conversely, Schrader and Gopfert's (1996) empirical findings indicate that when a buyer over-specifies the component design problem solution, problem structure, or problem-solving process, it leads to inefficiencies in the joint product development.

During our fieldwork, we observed that innovation is also another benefit to supplier involvement. We visited a braking system supplier that had just been given more responsibility in the design process. For more than 30 years it had successfully developed and produced under the tight specifications of the auto assembler. Under the new regime it could, for the first time, access the

CAD central data files and inspect the broader environment surrounding its subsystem. As a result, the supplier developed, tested, and submitted a new design that could save 20% in costs, if they were allowed to move a critical seal two inches away from a source of heat.

Greater supplier involvement naturally increases the number of interdependent tasks across the buyer-supplier interface. By definition, the buyer cannot reduce the requirements for coordination by self-containing the tasks, and therefore needs to instead increase the coordination capacity of the relationship (Galbraith 1977). This can be accomplished by investing in CAD data exchange with the supplier. Hence:

> **Hypothesis H3:** Automakers make a more extensive use of CAD technologies with suppliers with greater involvement in the design process.

4. TRANSACTION COSTS RISKS OF CAD USE

The interfirm use of CAD tools brings a complexity not found in traditional arrangements. Some vulnerability arises from the associated specific investments, and some is the result of the greater transparency that develops across firm boundaries. Sensitive information is difficult to protect without stifling engineers' creativity, and using CAD increases the speed and scope of information flow. Information can be leaked to competitors or appropriated by the supplier, and contracts or other monitoring devices are ineffective in joint design, where outcomes are difficult to specify in advance and inputs and outputs are difficult to observe or measure. We therefore propose that buyers will avoid "electronic partnerships" when these contracting risks are high.

Technological uncertainty refers to the buyer's own inability to accurately forecast the future technical or design innovations for the component (Heide and John 1990; Walker and Weber 1984). Technological uncertainty is high when a product exhibits frequent improvements in key functionality, frequent product or process innovations, as well as frequent price/performance ratio improvements (see appendix). In such a situation, the market supports multiple potentially conflicting designs without any dominant or stable one yet emerging (Tushman and Anderson 1986). Their limited cognitive capabilities and narrow domain of expertise make it difficult for engineers to anticipate future developments, settle on one supplier's technological solution, and plan or adapt their own internal processes.

To deal with this kind of uncertainty, firms can wait and see whether one supplier's design stabilizes and becomes an industry standard. This strategy is more likely when the component's underlying technology is irreversible and indivisible. Alternatively, firms can outsource to the multiple candidates if the component exhibits sufficient modularity. In either case, however, we propose that firms will deal with technological uncertainty through no or loose coupling with any given supplier and less investment in joint design (Balakrishnan and Wernerfelt 1986). By avoiding specific investments into one supplier's technological solution (including investments associated with CAD use), buyers minimize the risk of technical obsolescence and maintain the flexibility to terminate a relationship and switch to another supplier with more appropriate technological capabilities (Quinn and Hilmer 1994; Richardson 1996). We therefore propose:

> **Hypothesis H4:** Automakers make more extensive use of CAD technologies with suppliers for components under lower technological uncertainty.

Thin supply markets. As noted earlier, implementing CAD exchange with a supplier involves making specific intangible investments in the relationship. The buyer is at greater risk with respect to these investments when it is difficult to replace or substitute the supplier, as they open the door to potential appropriation by the supplier (or leakage to competitors). A thin component market (high market concentration) increases the buyer's dependence on the supplier as it can no longer rely on the threat of switching to another supplier to induce non-opportunistic behavior.

This is consistent with the classic economic argument that thin supply markets expose buyers to potential supplier opportunistic behavior. A recent laboratory experiment by Dutta and John (1995) reveals that a supplier that controls a market with a monopoly position is more likely to engage in price hikes than a supplier that shares the market with another supplier. Heide and John (1992)

find that more dominant firms (i.e., less dependent) can extract safeguards in a relationship. In other words, any small-numbers bargaining situation introduces the potential for opportunistic exploitation.

Nobeoka (1996) also suggests another risk associated with thin markets. In a concentrated market, the same few suppliers typically cater to most large car makers, thereby increasing the risk of information leakage from one customer to another (Nobeoka 1996). This is a situation where we suggest the "transaction costs" risks may exceed the "production costs" benefits of using CAD tools with a supplier. Hence the following hypothesis:

> *Hypothesis H5:* Automakers make more extensive use of CAD technologies with suppliers operating in less concentrated upstream markets.

Supplier dependence. We also propose the converse proposition, that a dependent supplier is less likely to behave opportunistically and more likely to reciprocate the buyer's investments in human and social capital to further promote codesign exchanges. The supplier does not want to loose the business from a critical customer (i.e., the supplier business economically depends on this buyer). It may accept the buyer's influence regarding some key decisions, in particular those related to information technology choices (Porter 1980; Provan and Gassenheimer 1994; Scherer 1980). Hart and Saunders (1997) develop a parallel proposition for the effect of supplier dependence on EDI adoption: "The greater the supplier dependence on buyer resources, the greater the buyer's capacity to influence supplier EDI adoption." The same reasoning leads to the hypothesis:

> *Hypothesis H6:* Automakers make more extensive use of CAD technologies with more dependent suppliers.

The investments a buyer makes and which are dedicated to a given supplier are, in general, at risk unless there exist some form of safeguard. The traditional "structural" safeguards, i.e., vertical integration or contracts, are undesirable or infeasible in our empirical context of codesign, i.e., a situation where the specialized expertise is embedded in supplier firms and where the input, output, and creation process itself are difficult to assess, observe, and monitor. McNeil (1980) and Heide and John (1990), however, suggest the existence of other safeguard mechanisms in the form of the social processes and norms of behavior within which the relationship is embedded. These "relational" safeguards contribute to reducing the buyer's uncertainty about the future behavior of the supplier.

As noted by Bensaou and Anderson (forthcoming), "a common misconception of transaction cost economics (TCE) is that it asserts that actors are inherently opportunistic. An accurate statement is that TCE asserts that it is difficult to determine which actors are in fact trustworthy (Williamson 1993)." We propose that firms may rely on their own positive as well as negative experience within a relationship to calibrate their exposure and assess the supplier's trustworthiness. Barney and Hansen (1994), for instance, suggest that some partners are seen as "hard core" trustworthy, independent of whether or not governance mechanisms exist to protect potential vulnerabilities. This "strong form trust does not emerge from the structure of the exchange, but rather, reflects the values, principles, and standards that partners bring to an exchange" (p. 179). On the other hand, Jap and Anderson (1999) recently studied the process of vilification in a relationship and empirically showed how "mere perceptions of the focal party are capable of poisoning collaborations and sending the relationship into decline over time. Coming to a conclusion that the other side has begun operating in bad faith is quite dangerous to the relationship" (p. 29).

From the channel literature, we identified three attributes of the social climate and norms within a relationship that appear to have particular relevance. These reflect what McNeil refers to as "relational norms," i.e., norms directed toward maintaining the relationship as a whole and curtailing behavior promoting the goals of the individual parties': mode of conflict resolution, sense of fairness, and perception of mutual trust (McNeil 1980; Kaufman and Stern 1992). The dominant mode of conflict resolution within the relationship defines a "bilateral expectation of the willingness to make adaptations as circumstances change. It represents for the buyer an insurance that the relationship will be subject to good-faith adjustments and that conflict will not degenerate into a vicious cycle and hostility" (Heide and John 1992). A sense of fairness in the way benefits and the burden are distributed within the relationship defines a similar bilateral expectation and also constitutes a safeguard against exploitative use of the CAD exchange and contributes to a virtuous cycle of engagement and commitment (Frazier, Spekman and O'Neal 1988).

Mode of conflict resolution. Conflict is one of the most widely studied phenomenon in interorganizational relations due to its ubiquity and potential destructiveness (Anderson and Weitz 1992). It can be costly for a manufacturer in time and money, especially when the courts are involved. Interdependence and divergent goals are fundamental realities of buyer-supplier

partnerships, and naturally conflict is inevitable and recurrent. Without interdependence, exit from the relationship would be costless and conflict would not occur. While some researchers argue that conflict need not be disruptive and can be constructive, Kaufman and Stern (1992) focus of the role of the process of conflict resolution. A conflict situation can either be resolved in a confrontational and adversarial manner or in a collaborative and problem-solving manner. Kaufman and Stern describe in detail the vicious cycle by which one conflict situation resolved in a confrontational and adversarial manner leaves hostility and sets the stage for the next conflict episode. It can evolve into feelings of bitterness and anger potentially escalating to the termination of the relationship. They note that the source of the retained hostility lies in the conflict resolution process. Just as liking increases over a series of successful interactions, a collaborative and problem-solving mode of conflict resolution evolves into a virtuous cycle that sets expectations as to the appropriate behavior during a future conflict episode. Conflict episodes and more importantly their mode of resolution, therefore, provide a buyer with information on the supplier's attitude, mode of operations, willingness, and predisposition to compromise. Hence we propose:

> *Hypothesis H7:* Automakers will make more extensive use of CAD technologies in relationships where conflict resolution is based on a problem-solving approach rather than confrontation.

Fairness. Asymmetry is another fundamental and natural feature of vertical relationships. It creates potential for exploitation by the more powerful firm. The powerful buyer or supplier may ignore the other party's complaints about injustice and the vulnerable party typically has few avenues for redress. It will experience increased hostility, unfavorable affective reactions which may lead to more conflict culminating in the termination of the relationship or in opportunistic behavior, i.e., self-interest with guile (Frazier 1983; Frazier, Spekman, and O'Neal 1988). Since the buyer cannot use traditional safeguards such as vertical integration or contractual protection, it must rely on its sense of the supplier's fairness and restraint to avoid being mistreated (Anderson and Weitz 1992; Heide and John 1988). Buyers are therefore, of necessity, concerned about the general sense of fairness that naturally emerges within the relationship.

In particular we expect distributive fairness, i.e., their perception that benefits (and burden) are divided within the relationship in proportion to each partner's respective contributions and inputs, to enhance the quality of the relationship and promote a virtuous cycle of mutual engagement and commitment to the relationship. Anderson and Weitz (1989), for instance, observe that suppliers with a reputation for fairness engender greater trust and expectation of continuity. Kumar, Scheer and Steenkamp (1995) empirically found a positive link between distributive fairness and relationship quality. These observed habits and norms of behavior contribute to reducing the buyer's uncertainties about the intentions and future behavior of the supplier and encourage specific investments when needed. We therefore propose:

> *Hypothesis H8a:* Automakers will make more extensive use of CAD technologies in relationships where they experience a greater sense of fairness in the sharing of benefits.

> *Hypothesis H8b:* Automakers will make more extensive use of CAD technologies in relationships where they experience a greater sense of fairness in the sharing of burden.

Mutual Trust Hart and Saunders (1997) describe the importance of trust in EDI use. They note that trust increases the probability that a buyer will expand the amount of information sharing through EDI. We expect the same to hold true with CAD technologies. They also highlight the importance of trust during the adoption phase and implementation over time (p. 30). Just as for EDI, many of the benefits and risks associated with the use of CAD tools with a supplier are difficult to anticipate at the adoption or implementation stages. It is by way of the cumulative and cospecialized investments made in human and social capital that buyers (and suppliers) gain experience and insights on how to better leverage the technology within the specific context of the relationship. Engineers who trust each other are willing to share relevant ideas, clarify goals and problems, and move down the learning curve together (Jap 1999; Moorman, Zaltman and Deshpande 1992; Zand 1972). A perception of mutual trust, therefore, contributes to reducing the buyer's uncertainty about the supplier's general motives and predisposition to committing the necessary investments to make the "electronic partnership" work. Hence the hypothesis:

> *Hypothesis H9:* Automakers will make more extensive use of CAD technologies in relationships where they perceive a greater sense of mutual trust.

4.1 Control Variables

U.S.-Japan differences.   Bensaou and Earl (1998) report that "Japanese firms have been lagging behind their Western counterparts in organizational computing not so much in the manufacturing control area or use of mainframes and large internally developed applications, but rather in the domain of white-collar and knowledge workers" (p. 173). Accordingly, we hypothesize a lower level of CAD use in the Japanese sample.

> ***Hypothesis H10:*** Japanese automakers make less extensive use of CAD technologies with their suppliers than their U.S. counterparts.

Market growth. Prior empirical work (Jap 1999) has shown a positive relationship between market growth and the incentive to build a partnership between the two partners. The market for some components and their underlying technology may exhibit high growth, what Jap (1999) refers to as pie-expansion opportunities, while others experience stagnating or even declining demand. Growing markets can absorb demand for the buyer and supplier products and provide the resources necessary to support the relationship (Starbuck 1976). When the market is growing, uncertainty is reduced and there is an incentive to work closely together and make the necessary investments to expand the size of the pie and effectively exploit available resources and opportunities, including new coordination technologies. We therefore expect:

> ***Hypothesis H11:*** Automakers will make a more extensive use of CAD technologies with suppliers in higher growth component markets.

Buyer's product range. Empirical research shows a positive relationship between firm size and innovation adoption behavior in general (Aiken and Hage 1968), and between firm size and EDI adoption in particular. These findings indicate that firms do not adopt technology because of their size per se, but because size offers economies of scale and scope, and sufficient opportunities to justify the investment in the use of a new technology. We, therefore, propose that automakers with a broader range of models are more likely to justify a high level of investment in CAD technologies. We developed a dummy variable to distinguish between the full range producers in our sample from the narrow product line competitors who focus on fewer product segments. We accordingly hypothesize:

> ***Hypothesis H12:*** Automakers with a broad model range will display a more extensive use of CAD technologies with suppliers than those who have narrow ranges.

5. PERFORMANCE IMPLICATIONS OF CAD USE: TESTING FOR A TASK-TECHNOLOGY INTERACTION

Under which conditions does CAD use make a difference in the quality of interorganizational coordination? We asked buyer engineers to report their satisfaction with the quality of coordination and information exchange along seven attributes.

Contingency theories such as the information processing framework (Galbraith 1977) explain how organizations match coordination mechanisms to tasks; a proper fit results in high performance. Conceptually, we agree that (1) there is no one best way to organize CAD use and (2) that any way of organizing is not equally effective under all conditions (Galbraith 1977). Buyer-supplier coordination can be enhanced by combining a variety of mechanisms, some organizational, some technological, some social (Bensaou and Venkatraman 1995). CAD technology is not equally effective under all conditions and greater performance is derived when the use of CAD is well "matched" to the information processing requirements of the task.

Fit as an Interaction Effect. We agree with Shoonhoven (1981) and Keller (1994) that most contingency theories are imprecise and that most empirical tests of such hypotheses do not clarify what is meant by fit, match, or alignment. Such conceptualization affects the hypothesis building and testing processes (Venkatraman 1989).

Based on Shoonhoven's findings and our own fieldwork, we choose to conceptualize fit as mediation. Engineers admit that they don't see CAD tools as necessarily useful for every task or design situation. "Sometimes the system gets in the way. It depends

on what kind of design you are working on. Is it a brand new design? Do you have to simply change the plug-ins to an already tested design?" We hypothesize that CAD's effect on satisfaction will vary with task analyzability and routineness (Thompson 1967). We express this interaction effect as a multiplicative function, whereby the effect of CAD use on satisfaction is modified by higher values of task analyzability or routineness.

$$Y = a0 + a1\ X + a2\ Z + a3\ X * Z + e \quad [1]$$

where Y = satisfaction, X = CAD use, and Z = task analyzability or routineness.

Hypothesis 13a: The more extensive the use of CAD technologies with a supplier, the greater the buyer's engineers' satisfaction with interorganizational coordination.

Shoonhoven further identifies two additional problems with contingency theory we avoid in this study: a sometimes misplaced assumption of linearity and its implicit assumption that contingency relations are symmetrical. We released the assumption of linearity and adopted the same analytical approach. Shoonhoven finds that decreasing centralization and standardization decrease effectiveness when uncertainty is low, but increase effectiveness when uncertainty is high. Similarly, we hypothesize:

Hypothesis 13b: The effect of the use of CAD technologies on the engineers' satisfaction with coordination performance is non-monotonic over the range of task analyzability (and task routineness) observed.

Hypothesis 13c: When task analyzability (routineness) is low, increases in the use of CAD tools will have a positive influence on satisfaction with interfirm coordination.

Hypothesis 13d: When task analyzability (routineness) is high, increases in the of CAD tools will have no or a negative influence on satisfaction with interfirm coordination.

A coefficient a3 that is significantly different from zero and large, however, does not provide information on the shape of the effect. We therefore graphed the partial derivative of equation [1] with respect to X (see Shoonhoven 1981):

$$dY/dX = a1 + a3\ Z \quad [2]$$

Equation [2] indicates that the effect of the use CAD technologies X on satisfaction Y is a function of task characteristic Z as well as the values of a1 and a3. A graphical representation (see Figure 2) illustrates how satisfaction changes with greater use of CAD over a range of task characteristics. A line representing equation [2] crossing the horizontal axis indicates the existence of a non-monotonic effect, and the intersection identifies the point of inflection at which the effect of CAD on performance reverses.
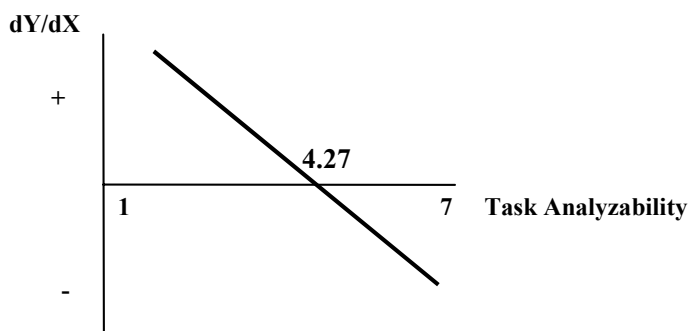

Figure 2. The Effect of Task Analyzability on the Relationship between CAD Use and Performance

Covariates. We set out to understand when using CAD between firms impacts engineers' satisfaction with coordination. We recognize, however, that other factors may also affect satisfaction, so we include in the analysis a set of covariates. Specifically, we hypothesize that mutual understanding, trust, a problem-solving mode of conflict resolution, the supplier's involvement in design, and the amount of time engineers spend dealing with the supplier are all associated with higher satisfaction. On the other hand, we anticipate a negative effect of conflict on satisfaction (see the appendix for measures and Table 2 for results).

6. RESEARCH METHODS

Operationalization of the Constructs. To test the hypotheses (see Figures 1 and 2), we either used measures previously validated in research settings or developed operational measures based on our fieldwork. The questionnaire was assessed for content validity through interviews and focus groups with engineers in Detroit and Tokyo. Respecting Nunnally's (1978) recommended procedures, we developed multiple items for each construct when possible. Sampling followed the same procedure in all companies. A senior executive in the central engineering division first selected a set of components under his or her responsibility from a stratified list of 50 components prepared by the researchers (to avoid selection bias). For each selected component, the executive identified engineers to whom questionnaires were sent. The final decision of which supplier and part number to choose were at the informant's discretion. The sample of companies includes the big three firms in the United States and the 11 firms in Japan in operation in 1991, the time of the data collection. The total data set comprises 194 responses (total response rate of 43%), each questionnaire representing a unique component-dyad pair, where the controlled range of components in the sample contributes to variance in products, technology, and market characteristics, and the variety of buyer-supplier dyads in both countries contributes to variance in suppliers and relationships.

Measurement Overview: We summarize the operationalization of each construct in the appendix. We used exploratory factor analysis to assess unidimensionality, and we used other variables to test for convergent and nomological validity. Reliability of the scales was assessed with Cronbach alpha; virtually all multi-item measures met or exceeded Nunnally's threshold of .7 for basic research.

7. MODEL ESTIMATION AND RESULTS

Model estimation. We used multiple regression analyses on the pooled sample to test the hypotheses. To test for the technology-task interaction, we used the two-step analytical approach proposed by Shoonhoven (1981). First, we conducted a multiple regression analysis with "satisfaction" Y as the dependent variable and a set of independent variables, including "CAD use" X as the main effect variable, "task analyzability" Z as the moderator variable as well as the other suggested covariates. We ran the analysis twice (with task analyzability and task routineness separately as they are highly correlated: .3 at p < .0001). Although we were testing for the interaction between technology and task, we needed to determine the explanatory power of the interaction term (i.e., the sign and significance of coefficient a3) after controlling for the main effects of the two main variables X and Z. In other words, even without any theoretical hypothesis to support the main effect of task analyzability (and task routineness) on satisfaction, Z must be a main factor into equation [1].

Results. Table 1 reports the regression analyses for hypotheses H1 to H12, and Table 2 the results for hypotheses H13a to H13d. The tables show full equation unstandardized regression coefficients for the interdependent variables entered simultaneously. Figure 2 displays the shape of equation [2] for task analyzability (the same shape is obtained for task routineness; the line crosses the horizontal axis in a different place).

The R^2 of .32 for the first set of hypotheses and of .64 for the second indicate satisfactory explanatory power. The individual coefficients are all consistent with our hypotheses. Both the "production costs" benefits and "transaction costs" risk rationales yield strong results. Technological uncertainty, however, does not have an apparent impact. As for the control variables, the results confirm that firms with a broader product range in general display a more extensive use of CAD technology with their suppliers. The Japanese environment exhibits lower levels of CAD use with suppliers across the board. In spite of the size of this effect, it appears to be confined to the intercept. A Chow test indicates that the two national subsamples are rendered poolable with the simple addition of a dummy intercept term.

CAD use is significantly and positively correlated with engineers' satisfaction with coordination, consistent with hypothesis H13a. Also, in line with hypothesis H13b, we find that the technology-task analyzability interaction is significant and negative. As we assumed, either task characteristic per se does not have a significant main effect. However, from this we can infer only a decreasingly slope expressing the change in satisfaction, given a change in level of CAD use over the range of task analyzability (or task routineness). We cannot, however, determine whether the slope changes sign. Resolving equation [2] with the regression coefficients in Table 2 (see Figure 2), we find the point of reversal at which an increase in CAD use has no effect on satisfaction:

Table 1. Results: Antecedents of CAD Use

Hypothesis (expected sign)	Independent Variable	Unstandardized Coefficient	Standard Error	t-value
Production Costs Benefits				
Task Features Which Demand Buyer-Supplier Coordination				
H1 (+)	Level of product customization	.30	.12	2.46**
H3 (+)	Supplier involvement in design	.77	.21	3.64****
H2 (+)	Frequency of design changes	.20	.08	2.21**
Transaction Costs Risks				
Technological Uncertainty				
H4 (-)	Stable or dominant product design	-.13	.10	-1.29
Relationship Safeguards: Supplier dependence, power				
H5 (-)	Supplier market concentration	-.02	.007	-2.67***
H6 (+)	Supplier dependence	.17	.1	1.64*
Relationship Safeguards: Social norms and relational climate				
H7 (+)	Conflict resolution mode	.37	.17	2.13**
H8a (+)	Fairness in burden sharing	.23	.12	1.81*
H8b (+)	Fairness in benefits sharing	.25	.14	1.73*
H9 (+)	Trust	.23	.12	2.03**
Controls				
H10 (-)	Japan dummy variable	-.74	.29	-2.6***
H11 (+)	Market capacity	.39	.12	3.15****
H12 (+)	Buyer product range	1.19	.40	2.94****

R^2 .326
Adjusted R^2 .277
F value 6.651
p value .000
* p<.10 (one-tailed test)
** p <.05 (one-tailed test)
*** p <.01 (one-tailed test)
**** p < .005 (one-tailed test)

$Z = -a1/a3 = -.124/-.029 = 4.27$ (3.58 for task routineness). Since this calculated value is within the 1 to 7 range observed within our sample, we conclude that the use of CAD technologies has a non-monotonic effect on coordination satisfaction over the range of task analyzability and routineness. We find that CAD technologies have a positive effect on satisfaction in the range of task analyzability below 4.27 and a negative effect when task analyzability is greater than 4.27. We obtain a similar result for task routineness (the point of inflexion is at 3.58, also within the 1 to 7 range of values observed).

All the covariates are highly significant and in the direction proposed. Engineers' satisfaction with coordination performance is positively associated with mutual understanding, trust, a collaborative mode of conflict resolution, supplier involvement, and the amount of time engineers spend dealing with the supplier, while we find a negative association with the level of conflict.

Table 2. Results: Antecedents of Coordination Performance, Effect of Task

Hypothesis (expected sign)	Independent Variable	Unstandardized Coefficient	Standard Error	t-value
Main effect of CAD use				
H1 (+)	Index of extensiveness of CAD use in relationship	.11	.04	2.20**
Main effect of task analyzability				
H5 (-)	*Design task analyzability*	*-.00*	*.004*	*.99*
Interaction effect between task and technology				
H6 (-)	Multiplicative term (X*Z)	-.03	.01	-1.98**
Other antecedents				
H11 (-)	Mutual understanding	.43	.05	7.7****
	Trust	.21	.05	3.95****
	Collaborative conflict resolution mode	.17	.06	2.58**
	Supplier involvement in design	.175	.08	2.18**
	Amount of time spent dealing with supplier	.10	.04	2.064**
	Conflict level	-.14	.05	-2.84***
	R^2	.637		
	Adjusted R^2	.615		
	F value	28.875		
	p value	.000		

8. DISCUSSION, LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

8.1 Discussion

Taken as a whole, these results confirm our hypothesized pattern of tradeoff between production cost benefits balanced by transaction costs risks, mitigated by safeguards.

Consistent with work on design, task and contracting structure (Baldwin and Clark forthcoming; Eppinger et al. 1994; Novak and Eppinger 1998), the results support our hypotheses of "technological determinism." The component's technical attributes affect the use of CAD with suppliers; particularly, automakers make greater use of CAD tools with suppliers for components with a higher frequency of design changes and higher levels of customization.

The results also support Jap's (1999) findings that greater environmental demand motivates buyer-supplier collaboration and facilitates the buyer's willingness to create idiosyncratic investments with suppliers. Growing markets offer the potential for "pie-expansion," i.e., the "collaborative process...designed to expand the size of the joint benefit pie and give each party a share of an incrementally greater pie that could not be generated by either firm in isolation" (p. 2).

We also find that CAD use is part of a broader decision of how much to involve a supplier in the design process to begin with. Once buyers choose to involve a supplier, they commit the investments necessary to support the joint activities.

Consistent with dependence research (Emerson 1962; Hart and Saunders 1997), we find that buyers avoid making additional specific investments in already-vulnerable relationships. Yet, we find that a relationship's social climate and norms of behavior

are also positively associated with CAD use. Buyers use these social experiences to assess the supplier's likely future behavior; positive experiences favor CAD use. The cross sectional nature of the research design, however, does not allow us to infer the direction of causality.

The country dummy has strong effects. Japanese automakers exhibit a much lower level of use of collaborative CAD use than their American counterparts. The simplicity of the effect is striking: indeed, the conceptual model holds across the two countries but at a systematically lower level in Japan. This finding agrees with Bensaou and Earl (1998), who report a lower use of IT in Japanese firms than American ones.

Broad product ranges were also correlated with CAD use. Whether from a large pool of suppliers or from having suppliers make parts for many different models, such buyers benefit from economies of scale or scope.

Technological uncertainty had an insignificant effect (although the negative sign is consistent with our hypothesis). Tests with squared terms and inspection of both subsamples reveal a consistent pattern without curvilinearity, suggesting either a truncation in our sample of components (few "low technological uncertainty" components) or a reality of the auto industry (few components have a stable design over five years).

This study finds that greater CAD use is associated with greater satisfaction with coordination. However, we found that the effect of CAD on satisfaction is modified by the level of analyzability of the engineers' codesign task. CAD use has a positive effect on complex joint tasks, while it is not perceived to be of value when the task is structured, well defined, and repetitive.

Although not the focus of this paper, we find that the quality of the social climate is strongly associated with engineers' satisfaction.

8.2 Limitations and Suggestions for Future Research

Several limitations to our study should be noted. First, this is an exploratory examination of factors explaining variance in the use of CAD technologies with suppliers that is limited to the automobile industries, though we expect similar effects in the manufacturing of other complex products. Subjective measures of product customization and design change frequency can be seen as weak surrogates for components' architectural interdependence. There is a need for more objective and technical measures. Novak and Eppinger (1998) offer a good example of such an effort. They used mechanical attributes of the different subsystems as measures of architectural complexity.

This study does not attempt to capture the interaction effect between the use of CAD applications and other forms of human coordination, e.g., face-to-face meetings, guest engineers, liaison roles. Our field observations suggest a strong complementarity at lower levels of task analyzability and routineness, i.e., when engineers faced the more complex, ill-structured, and often changing tasks. These are typically the creative tasks and not the drafting activities, which are in reality a major part of a design engineers daily work. On the other hand, this study does not focus on the effect of individual level factor in the adoption/rejection and effective use of CAD technologies. Following the work of Kraut et al. (1998a) we suggest further exploration of importance of social influence in the effective use of CAD in a relationship. As shown, researchers should consider both utility and normative factors, which may operate at the individual firm as well as relationship levels.

Our research design is not intended to capture the dynamic aspect of the investment decisions over time and the interaction between the buyer's and the supplier's CAD investment decisions. As Hart and Saunders (1997) suggest, the dependence structure between the buyer and supplier may evolve over time. Similarly, the quality of the relationship and the need for safeguards may change over the relationship lifecycle as it develops from exploration and buildup to maturity or decline (Jap 1999). Longitudinal studies would be useful, as well as dyadic data (from both supplier and buyer), which would permit further examination of alternative specifications.

The central relationship between technology and coordination performance also needs closer examination. A micro level analysis *in situ* of actual design processes (as opposed to the retrospective perspective offered by our informants) would further clarify the reasons why the effect of CAD technology reverses over the range of task characteristics. Another avenue for further research

is the study of the decision making process that leads to the investment in CAD use (or not) in a relationship. This paper relies on a *post hoc* analysis of practice as reflected in a cross section of relationships.

A key contribution of this study is that it conceptually identifies and empirically validates the dual role of information technology when used across organizational boundaries (see also Kraut et al. 1998b; Steinfeld, Kraut and Plummer 1995). On the one hand, it is a powerful tool to increase coordination capabilities within a relationship, even for non-algorithmic and knowledge-based task, yet on the other hand, it creates a vulnerability within the relationship. We believe this is a distinctive feature of information technology which, has not been identified before, neither within the intraorganizational context nor in the EDI context where the coordination of algorithmic tasks and the controlled exchange of structured data can be accomplished with general purpose investments.

This analytic distinction between these two roles has theoretical and managerial implications. What is the interaction between the two sets of drivers? Should firms invest in CAD exchange with suppliers when they face simultaneously strong production costs pressures and severe transaction costs risks and vulnerabilities? Manufacturers of complex industrial products are increasingly moving the design and manufacture of critical components and integrated subsystems to a few preselected suppliers. As information technology develops and further enhances the capabilities for electronic coordination and exchange of knowledge between firms, the production costs pressures increase. Closer relationships, however, imply greater buyer dependence and increased idiosyncratic investments, sources of vulnerability. This tension deserves further inquiry. There is a need to revisit the links between design architecture, task structure, and contracting structure.

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Appendix
Operationalization of the Variables

Constructs	Variables	Item (α)	Illustrative items and scaling
Level of inter-organizational use of CAD with a supplier	*Index of CAD*	4 (.83)	Cumulative index, from 1 to 7, for the range of types of documents exchanged electronically between the buyer supplier: regular documents, paper drawings, two-dimensional CAD, three-dimensional wireframe, three dimensional surface three-dimensional solid to analysis results.
Task Features	*Frequency of design changes*	1	Reversed seven-point Likert scale ranging from frequent specification changes to rare specification change
	Level of product customization	4 (.71)	Was measured using seven-point interval scales ranging from: standard product with a low level of customization to specialized product with a high level of customization; technically simple to technical complex product; needs low engineering effort and expertise to needs significant engineering effort and expertise; requires small capital investment from suppliers to require large capital investments
Environmental Capacity	*Component market capacity*	1	Market growth level measured using a seven-point interval scale ranging from a declining to a growing market for the component
Environmental uncertainty	*Technological uncertainty*	4 (0.85)	How likely will major changes occur in the component in four areas (i.e., functionality improvements, major product innovations, major manufacturing innovations, price/performance ratio improvements) in the next five years—from very unlikely to very likely—seven-point interval scales
Relational Safeguards: Supplier dependence	*Concentration of upstream market*	2 (0.68)	Estimate of the North American or Japanese market share of the top five suppliers of this component combined (and of the first of the top three suppliers)
	Supplier dependence	1	Seven-point Likert scale on how economically significant is your business to this supplier from extremely non-significant to extremely significant
Relational Safeguards: Social norms	*Conflict resolution mode*	1	Extent to which major past disagreements between the two firms have been resolved in an adversarial or collaborative way. This indicator is measured using a seven-point interval scale ranging from adversarial, based on confrontation to collaborative, based on problem-solving and negotiation
	Fairness in burden (benefits) sharing	1	Extent to which their exists an equal sharing between the two firms of—burden and—benefits. Seven-point interval scale ranging from your firm has more of the share, to this supplier has more of the share
Coordination performance	*Satisfaction with information exchange*	7 (.94)	Perceived satisfaction with the supplier along seven criteria, e.g., the quality, amount and accuracy of the information exchanged. Each indicator was measured using seven-point interval scales ranging from: not very satisfied to extremely satisfied.
Institutional context	*Task Routineness*	2 (.79)	Extent to which you basically perform repetitive tasks, and extent to which you do the same tasks in the same way most of the time.
	Task Analyzability	4 (.71)	Extent to which there is a clearly known way to do your job when it relates to this supplier. The four indicators measured using seven-point interval scales ranging from strongly disagree to strongly agree for the first two indicators, from very detailed to very broadly defined, and from very vague to very clear for the other two indicators.