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Collaborative Information Systems

A Comparison of the Electronics and Facility Design Industries

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The creation of a product is a complex, highly-interdependent process. Typically, no individual possesses all of the required knowledge and skills, so design teams that include participants from each required domain are formed to collaborate and jointly create a single product. As projects become increasing complex, additional participants are added to the team. While this approach supplies the needed expertise, it also introduces a significant coordination burden and decreases the overall efficiency of the process. This report explores how a collaborative information system (CIS) can be used to reduce this coordination cost and contrasts the limitations encountered as this model is applied to different industries.

1. Introduction

An effective information system provides users with the information needed to respond to environmental requirements. To stay useful, as demands change, the information system must also evolve. These demands range from single pieces of information that an individual can act upon, to complex systems that bring together knowledge from many organizations. Over the last two decades, advances in technology and communication have created a capability, and forces shaping the business environment have created a demand, for collaborative information systems (CIS) that integrate and coordinate information from diverse sources.

In this report, we examine the business megatrends at work in the late 20th century and their effect on the evolution of information systems, defining a new model to support collaboration. We then present two state-of-the-art systems being developed for the electronics design and facilities engineering industries, and analyze how well the CIS model fits these applications. Finally, we outline the underlying technical hurdles and present some caveats regarding the applicability of CIS systems.

2. Business Megatrends

Interest in the development of CIS can be traced to strategies for effectively responding to business megatrends that are reshaping design-intensive industries:

- **Responsive systems** — shortening the design/production cycle is necessary to bring products (or facilities) to market sooner, resulting in a competitive advantage. A CIS system can provide the improved coordination required to move from a sequential design process to concurrent (or fast-track) engineering.
- **Project-wide coordination** — engineers optimize their designs based upon their perspective about what is important in a product. Enabling individual participants to evaluate the impact of their decisions on overall project goals facilitates global optimization. Improved coordination is needed for design teams to effectively respond to changes, which have become the rule rather than the exception, and minimize the inefficiencies introduced by collaboration.
- **Cooperative environments** — effective collaboration requires all members of the project team to work together toward a common goal — the success of the project. In the electronics industry, the vertical integration of many specialties brings the entire project team together into a single firm. In the facilities design industry, the economies of scale do not exist to support entire teams in a single organization. Although collaborators are typically drawn from separate firms, a CIS system permits horizontal integration, with complementary specialists forming a value-added partnership.
- **Global competitiveness** — design-intensive industries, particularly electronics and construction, have been the targets of intense foreign competition. Foreign firms have several business advantages (lower labor costs, greater investment in technological innovation, etc.), and U.S. firms compound the problem by clinging to a highly fragmented and specialized approach to business. For example, the waning competitiveness of the U.S. construction industry in the past 20 years has been well-documented, with productivity declining at a rate of 1% to 2% per year. Practically all observers agree that one of the root problems is poor coordination.

In light of these trends, the development of CIS systems takes on a much broader role than merely adapting an existing process to incorporate technological advancements. CIS systems harness new technology to support a fundamental changes in the nature of the design business that are necessary to insure long-term survival.

3. Evolution of the CIS Model

The changing nature of coordination requirements among human beings has been the driving force behind the creation and evolution of information and decision support systems. In the simplest case, an individual can make all required design decisions based completely on his or her own knowledge. But this situation is rarely found. Typically, the expertise of several specialists must be pooled together to form a design team. The complexity of collaboration between the teem members can be reflected in the evolution of the CIS model [El-Bibany 91] as explained in the following points.

3.1 Collaboration Requires Coordination

Collaboration adds a layer of complexity to the design process by introducing the need for coordination. Figure 1 illustrates a situation where two members of a design team collaborate on some aspect of a design. While the participants directly involved in the decision have benefited from their communication, they have created an isolated island of knowledge not available to a third person.

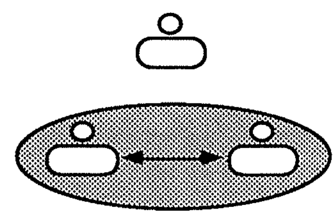

Figure 1
Separate Island of Knowledge Requiring Coordination

While designers may try to involve all affected parties when making collaborative decisions, their understanding of the ripple effects is limited, and important changes sometimes slip through the cracks unnoticed.

3.2 Meetings

Project teams often rely upon group meetings as their primary coordination mechanism, illustrated in Figure 2. Although meetings are an effective coordination tool for non-complex requirements, they are very expensive and inadequate for complex requirements. Also, the benefit of the group knowledge is only extended to meeting attendees.

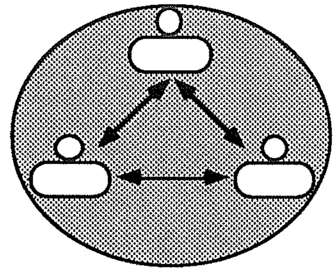

Figure 2
A Bigger, Expensive Island of Knowledge Requiring Coordination

3.3 Pooled Information Database

If the information dependencies between various participants can be characterized as pooled or sequential , a set of rules and a pool of data, represented in a central database, can help coordinate their requirements as shown in Figure 3. In an organization, this central database can take the form of culture, standards and rules, a paper or electronic database or a combination of all these forms. This central database records decisions made by individual participants and subteams in a standard format that can be used by all.

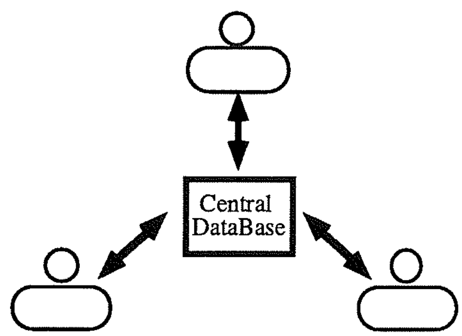

Figure 3
A Central Design Database

3.4 Monitoring Agents

The next level of complexity emerged from the need to coordinate among participants belonging to different trades under market pressure of time and quality. In case that these participants belong to the same organization with the same overall goal, a model of information dependency can be created. In this model, Figure 4, the organization tries to transfer all reciprocal information dependencies into sequential with a pool of dynamic data in the form of a central database. This central database, reflects decisions taken by various participants in a standard format.

The requirement to reduce the time and cost of interpreting the effect of a change on the various participants lead to the need of specialized AI agents representing each of the participants' knowledge. These agents can continually monitor the proposed changes, screening out the routine and highlighting important changes that will require action. Notice that knowledge-based systems forming the AI agents can neither be complete nor sound.

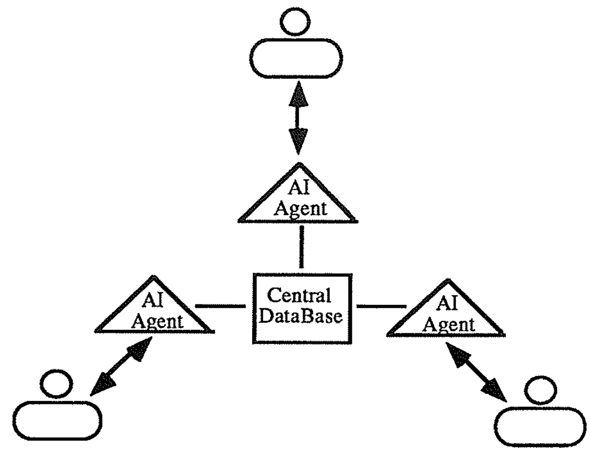

Figure 4
Knowledge-Based Coordination of a Central Project Database

3.5 Generic Coordination System

When participants belong to different organizations, with all legal and liability problems, a more generic coordination framework is needed as shown in Figure 5.

In this model, a generic and flexible coordination system would play the main role of coordination. The coordination system should have a generic representation to allow free interaction between all types of agents — human, machine, databases, knowledge-based systems, simulation systems, etc. A central project database is no longer considered the focus of the system. Databases are merely agents that contribute to the constraints imposed on the overall problem. The required flexibility of such a system calls for a low-level generic representation of knowledge.

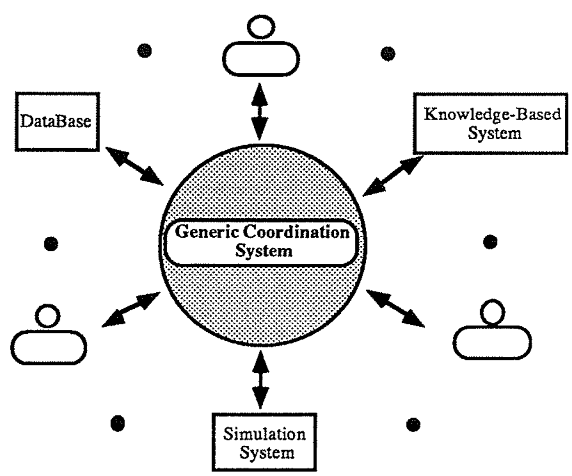

Figure 5
Generic Coordination of a Collaborative Project

4. Applications of the CIS Model

Although CIS systems will take advantage of rapidly advancing computer technologies, they must not be viewed as technical solutions being developed in a vacuum. Ultimately, any information systems is only useful if it "fits" the organizations that it is intended to support.

Two implementations of the CIS concept being developed at Stanford University help illustrate this point. The first system, *Next-Cut*, is being developed by the Center for Integrated Systems for the electronics design industry, where all design team participants typical belong to single firm. The second system, *ConCoord*, is being developed by the Center for Integrated Facility Engineering for the architecture/engineering/construction (A/E/C) industry, a much more complicated world where project participants are temporarily drawn from many specialty firms.

4.1 Concurrent Electronic Design: Next-Cut

The development of new products in the electronics industry provides a dramatic example of how sharing design information can create a strategic advantage.

The Team

- An electronic design firm traditionally has several different focus groups that must work together to effectively produce a product, often engineering, manufacturing, marketing, sales, and general management.
- The design team is stable over time. They have probably collaborated on similar projects before and will continue to work together on future designs. Communication norms have been defined, and information flow is likely pooled or sequential.
- The design team members work for a single firm and should share a common overall goal — firm profitability. While individual members may have subgoals, the common goal should dominate and insure cooperation.
- Design team members understand the benefit of coordinating product design and process design to lower production costs.

The Process

- Products of design process (electronic products and manufacturing process) are central to the business strategy of the firm.

- Quality of design must be good because it will be repeated thousands of times. Costly design flaws will be repeated over and over, shaving precious cents from unit profits.
- Efficiency and responsiveness of the design process is critical. Shortening the design cycle greatly increases the potential profitability of electronic components which historically have low product life cycles. A delay of a few months can lead to substantial losses in profit and market share.
- Many product design specifications are set at the start of the development process, but changes are inevitable as the product evolves and matures. The marketing group typically makes early decisions during the product inception stage, but the engineering group coordinates technical design. Finally, the manufacturing group designs the production process. As each of these groups modifies the product, other groups must be notified of the changes and evaluate their impact.

The Information being Managed

- While each group is concerned with information about the product, the types of information they need are different. For example a process engineer should know how the design of a new component will affect his manufacturing process and if new machines are needed. The finance person should be able to identify how much the new machine will cost and how profitability of the line will be affected. Marketing people should be able to see, as the design evolves, how the market will be for the features of the new product and the General Manager should be able to track how long it will take the design to reach market.
- Information is relatively free-flowing between collaborators. There are no proprietary or legal liability barriers.
- Most engineers and others are already using computers for their daily work. The initial barrier has already been broken down, and they can now more fairly judge the usefulness of further applications.
- The design follows a standard, predictable route from design to production. If there is a problem it is easy to determine who is at fault.
- The information system's major usage is managing technical uncertainty.

CIS Goals

- Overall goal of CIS is to bring marketing, manufacturing and design information together so all players (all engineers) can use toward single goal.
- Since the goal of all parties is for product profitability, it is assumed that if given the appropriate information desired behavior will follow.

The Next-Cut System

The Next-Cut system [Brown et al. 91] is built around a central shared database that combines information from and provides information to each group participating in the design team. Each radial spoke includes a customizable AI filter or agent that parses proposed design changes, determines whether a function will be affected by the change, and evaluates and reports on the ramifications of that change.

Next-Cut provides instant feedback and warns if changes introduced by a group propagate beyond the levels deemed acceptable by other groups. For example, if the participant of an integrated circuit extends his/her design beyond acceptable process technologies, a warning is immediately issued to the participant to warn of the possible violation. The participant then has the first opportunity to decide if the performance advantage is worth significant process changes. If the participant decides that the tradeoff if acceptable then the technical manufacturing engineers and project managers are flagged.

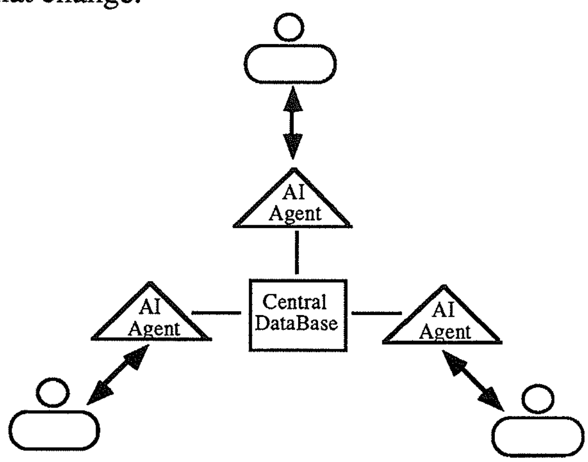

Figure 6
Overview of the Next-Cut System

Advantages

This instantaneous feedback and "time of change" analysis in Next-Cut greatly improves the product development cycle in many ways:

- resolving technical issues early in the design phase assures the availability of the broadest range of cheap, high impact solutions;
- involving all design team members in the change resolution process helps them buy into the final product concept;
- facilitating the shift from a sequential to concurrent design process shortens the development cycle without sacrificing design quality; and
- the shared design information system also creates a coordination advantage as all design members focus on how their decisions affect the profitability of the product rather than local optimization.

Factors affecting Acceptance

- **Can Do it** — If the top management accepts this system it can be implemented as a DeJure standard.
- **Want to Do it** — In position to recover implementation costs and can quantify benefits in terms of overall profitability.

- **Won't get too much resistance** — The electronics culture is full of young risk-takers who embrace technology as a tool. They, for the most part, already use computers and have ready access to data ports.

4.2 Integrated Facility Engineering : ConCoord

The facility design process provides another example of the advantages of CIS, but the underlying relationships between members of the design team are very different from the electronics industry and create a entirely new set of hurdles.

The Team

- The planning, design and construction phases of a single project — whether a road, a bridge, a building, or an industrial plant — are typically carried out by different planners, architects, and engineers, often working for different organizations. Even within a particular phase, such as design, the major structural, mechanical, and electrical engineering design tasks are likely to be performed by separate individuals and organizations. Owners cannot develop in-house expertise to deal with project coordination problems, so they call in outsiders.
- The design team members do not share a common overall goal. The owner is concerned with both the efficiency and quality of the design process, because he pays for the facility (both in the short-term during construction and in the long-term during operation) and uses the completed facility to support his primary business. Engineers and contractors have a very different perspective. They are providing a service for a fee and have no long-term stake in the efficiency or quality of the design. They are primarily motivated by desires to avoid responsibility for current and future mishaps and minimize their costs relative to billable hours.
- The design team is temporary and will share this collaborative relationship only for the duration of the project. Their firms may collaborated on similar projects before, but the specific participants have probably changed. Communication norms must be defined on the fly, and information flow is likely reciprocally interdependent.
- Design team members are not fully committed to the benefits of coordinating design and construction information to lower production costs. Owners have led the push for constructability, because they benefit the most. Engineers and contractors have been reluctant to cooperate, because they bear the costs of redesign and hesitate to admit that the design could be improved beyond their original proposals.

The Process

- The product of the design process (a facility) is not central to the business strategy of the firm (with the exception of real estate developers and hotel owners). Facility management is often viewed as a secondary support function, tolerated only on as-need basis.

- Quality of design should be good, but sup-optimalities are tolerated. Most facilities are viewed as being unique (which may not be as true as the participants believe), so design flaws that would be expensive to fix are not corrected.
- Efficiency and responsiveness of the design process is important, but not critical. Shortening the facility design/construction cycle allows manufacturers to start production earlier, but participants have learned to expect long delays. If time is essential, space (a somewhat generic commodity) can be rented.
- Design requirements are ultimately defined by the needs of the owner, but owners have little technical knowledge about facility design and often assume a passive role through the design/construction process. Although owners are ultimately in control, they don't have the technical or management skills necessary to be good coordinators.

The Information being Managed

- Information sharing between collaborators is inhibited by proprietary and legal liability barriers. All players add to common pool, but very concerned with tracking source - liability tracking. Information owned by separate firms, so construction info not readily available to designers. Conflicts of interest and proprietary concerns.
- Many collaborators are not using computers in their daily work. Design and coordination information is typically passed by voice or paper both within and between organizations. Even if analysis and design tasks are performed using computer tools, the results are rarely available in a digital, shareable form.
- Sources of error hard to pin down. Causes of error are harder to pin down due to the difficulty to track the source of the error. While task specialization has produced high quality results in many cases, the task of coordinating design information has been compounded. In an increasingly complex and time-pressured environment, the results can be disastrous. For example, coordination errors led to the 1981 collapse of the skywalk in the lobby of the Hyatt Regency Hotel in Kansas City.
- Technological uncertainty, in all but the very complex projects, is usually controlled at a low level. The main project uncertainty, however, stems from the complex coordination requirements. This affects the methods of design and construction. Design tend to be very conservative to allow for coordination errors.

CIS Goal in Facility Engineering

The main goals of CIS in facility engineering are:

- Coordinating human players and serve as knowledge exchange tool.
- Avoid decision conflicts that can lead to failures.
- Create historical record (change history), for future use and liability tacking.
- Provide basis for evaluating proposed changes (change-management).

These CIS should be developed with the industry requirements in mind and hence they should:

- be generic systems flexible enough to take into consideration the change of organization as well as coordination strategies and goals of different projects.
- consider that information availability does not guarantee desired behavior due to conflicting goals.
- allow to work with partial knowledge with explanation facilities clarifying their state of knowledge.
- allow the project participants each to use the system in the way that he or she is used to deal with project information and at the level of detail that the participant would choose.

The ConCoord System

ConCoord [El-Bibany and Paulson 90, El-Bibany 91] is a prototype project management system that uses constraint-management for coordination between project participants. ConCoord models three principal agents in the design process: the architect, the structural designer and the construction manager. ConCoord as a CIS follows the model of Figure 5.

Figure 7 illustrates the relationships between ConCoord's chief components. Knowledge about project objects forms the basic core. The constraints layer describes the relationships between the properties of the various objects that must be maintained. The connectivity layer ties together all parties collaborating on the project .

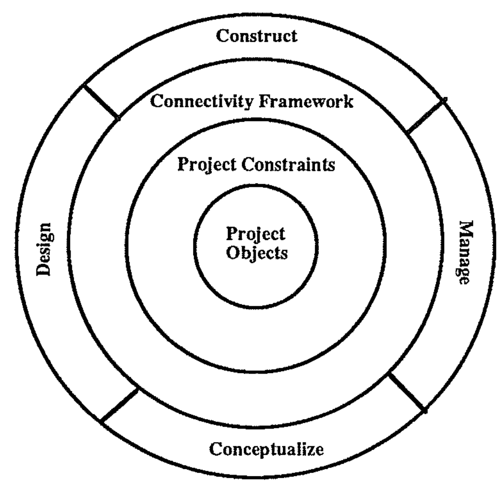

Figure 7:
Overview of the ConCoord System

As participants propose changes, new information requirements, constraints and field conditions are automatically propagated to other agents who need to know about them, while maintaining the constraints that were previously specified and remain unchanged. Design parameters are automatically adjusted to satisfy the new requirements if possible; if not, all parties concerned are notified immediately so that negotiations can proceed to find a mutually agreeable solution. ConCoord flags conflicts and assists in determining the cause of problems, allowing participants to focus their attention on solving the right problem in a better way. Users can query the integrated object knowledge base for the existence of certain relationships between the attributes of different objects and evaluate the global impact of proposed design changes.

Advantages

ConCoord improves productivity in the architecture/engineering/construction industry by:

- facilitating effective coordination and communication between design team members.
- providing construction process feedback early in the design phase.
- reducing design errors through early conflict identification and facilitated negotiation.
- advancing design/construction automation.

Factors affecting Acceptance

- **Can't Unilaterally Do it.** In a highly fragmented industry as discussed in the preceding points, DeFacto standards for such CIS is the only way for imposing standards. The more the industry adopts such CIS the higher its network externalities, and the stronger the force to mandate the use of these systems.
- **Want to Do it**. There is no motivation for individual organizations to use such costly systems. Implementation cost is high and the only beneficiary are the owners. Other participants, except for large organizations, are not in position to recover implementation costs.
- **Legal Obstacles**. This can be summarized by the following questions. Moving decision rights to the computer? Who's liable?
- **Will get a lot of resistance**. With all the technological advancements in the last 3 decades, the AEC industry remains the least affected. The culture of the various sectors hinder technological advancement. For example, architects still prefer the high touch over the high tech. Construction is an old and conservative trade very slow to respond to technology.

5. Technical Hurdles to CIS Development

5.1 The Need for Standards

For CIS to function as envisioned, standards must be developed to allow collaborative use of design information. Examples of these standards are:

- Information model - Project Data Structure — the representation of the information itself.
- Protocols for information passing — the language of communication.
- A data highway — Local- and Wide-Area Networks: the mechanism for communication.

5.2 Maintaining Technological Transparency

A CIS system should be flexible enough to allow users to perform tasks in the same way as they were performed independently. The CIS should add capabilities through access to information, but not restrict users or force relearning. Existing pieces of hardware and software should work independently and as part of the integrated system. This technology transparency goals requires interconnectivity standards to be devised for:

- Computation and analysis software
- Interfaces for viewing and editing data
- User workstations
- Network connections

5.3 Modelling and Working with Constraints in AI

The generic CIS model illustrated in Figure 5 is built on the concept of a powerful generic representational core. As adopted by ConCoord, this core is a powerful constraint-management system representing all possible knowledge in the form of mathematical constraints. Other domain logical constraints are represented in the form of metaknowledge managing the mathematical constraints. For dynamic updating of changes, the overall information structure is held in the form of assumption-based truth maintenance systems. Static information related to the project objects is represented in object-oriented databases with sophisticated transaction management capabilities. We notice that all these are still current research topics in the AI field and hence represent technical hurdles for these systems.

6. Conclusions

Few question the validity of the CIS concept — using advanced computer technology to help coordinate the information flow between diverse participants involved in a collaborative design/production process — but technological superiority is not enough to guarantee success. Any information system must fit the specific requirements of the group it supports and therefore must reflect the markets, the culture, and the norms of the business system already in place. Adding computer technology to a system with problems rarely fixes them — rather, it compounds them.

In the electronics industry, several critical factors are present that will facilitate the successful implementation of the CIS concept:

- **Appropriate fit** — the technical solution matches industry requirements.
- **Top management committment** — within a single firm, guided by a single objective, top management is in a position to get behind and full support the design and implementation of a CIS system.
- **Internal support** — if all members of the project team have a stake in project success, they will also support a CIS system that helps them optimize the global objective.

The AEC industry presents a very different picture. This industry could certainly benefit from CIS technology, but it is organized in a way that creates immense barriers to successful implementation:

- **Inappropriate fit** — while great needs exist, flaws in the basic system must be corrected before technology can be applied. The organization structures and legal environment currently in place have inherent problems that would probably be compounded by automation.
- **No top management committment** — facility design teams are temporary and drawn from many firms. In these relationships, no single top manager exists who can support and fully commit all key players to the CIS development process. While owners have the greatest incentive to take on this role, they have no effective way of imposing this goal on others. Success will ultimately depend on industry-wide cooperation, which historically has been very rare.
- **Little internal support** — architects, engineers, and contractors have little to gain, but will bear many of the costs incurred in moving from their current ways of

working to a CIS system. While technological transparency is a goal, some new hardware and software costs are inevitable. Also, cultural differences are likely to cause early attempt to sabotage the implementation process. Architects like drawing on paper; contractors like keeping their information private. Collaboration is a nice general goal for the system, but many will hesitate when it comes to personally implementing it.

CIS systems provide an effective means of accessing and coordinating design requirements, but providing a tool for coordination is not enough to guarantee the desired collaborative behavior of the project participants. Ultimately, if a CIS does not fit system-wide goals, it should not be implemented, even if it is technologically superior. The expected benefits will be far outweighed by the implementation and change-over costs, and the resulting system will be less effective.

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