MANAGING DESIGN CHANGES

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The DEFINITY® Communications System represents a commitment to protect customer investment in AT&T's private branch exchange (PBX) hardware. The DEFINITY Communications System family provides a premises-based migration path for customers who require from 40 to 32,000 lines. The DEFINITY Communications System development teams used two strategies to fulfill this commitment: First, we incorporated existing product designs wherever possible. Second, we designed most new hardware so it could be used in more than one system (e.g., PBX, voice mail). (See Panel 1 for definitions of abbreviations and terms.) These strategies resulted in a significant pool of common-hardware designs and eventually required changes to some product lines. Despite our planning, we lacked a change-management process to oversee the development of common hardware. To overcome this problem, we applied a customer-supplier model,[1] which improved our documentation, communication among the product-line organizations, and the method we use to coordinate change. The new process, which incorporates the best of existing practices, has enabled us to merge different product architecture and design organizations, reduce product-development intervals, and improve the quality of the product sold to our customers.

Introduction

Change in a complicated product such as a PBX must be properly managed and controlled to ensure the product's continued success. The product's design may be altered to:

- Resolve design deficiencies
- Enhance the product
- Adapt to the varying products and material purchased from outside vendors.

Although product-development organizations try to minimize how frequently they alter a product's design, they cannot eliminate change entirely. The factors that determine the difficulty of changing a product are:

- The product's complexity
- The size and nature of the organization that controls the product
- The product's stage of life
- The quantity in use
- How many different ways the product is being used.

The DEFINITY Communications System, a state-of-the-art PBX that contains complex circuit packs and equipment, is affected by all these factors. The product-development organizations must meet the challenges that change will bring, as they continue to deliver a quality product to the marketplace.

The DEFINITY Communications System product lines evolved as a result of merging the System 75 and System 85 PBXs. System 75 and System 85 are mature products serving customers worldwide. Much of the DEFINITY Communications System hardware is used in both System 75 and System 85; therefore, changes must be compatible with all three products. Assemblies of the DEFINITY Communications System product line are used in other product lines such as: System 25 (an AT&T PBX offering in the 30- to 150-station range), System 75 International, and AT&T's AUDIX (Audio Information Exchange) Service.

Merging System 75 and System 85 hardware with the DEFINITY Communications System product lines required changes to ensure feature transparency and a consistent user interface. The way design organizations managed change in the past did not work in the new DEFINITY Communications System environment. Poor communication between the many development organizations involved in the product's design eventually led to inadequate product testing, malfunctions during controlled introduction at customer sites, and suspension of product delivery.

Communication problems arose because each DEFINITY Communications System design and development organization used different methods and processes to manage change. It was crucial for the DEFINITY Communications System organizations to analyze the current process and put a new procedure in place as quickly as possible. The DEFINITY Communications System had been announced recently and was entering the stage of

Panel 1. Acronyms and Terms in This Paper

AUDIX — audio information exchange

Customer — the recipient (i.e., an individual, group, or another process) of information or material generated by another's work.

DCL — design change letter

DEFINITY Communications System — an AT&T private branch exchange offering 40 to 32,000 lines

EDI — engineering design information

Firmware — software that is programmed into read-only memory (ROM)

Hardware — the assemblies that comprise a system, such as circuit packs, backplanes, power supplies, and other equipment.

PBX — private branch exchange: a phone system on a customer's premises.

PQMI — process-quality management and improvement

RFA — request for approval letter

Supplier — an individual or group that provides information or material to a process, individual, or group.

System 25 — an AT&T private branch exchange offering in the 30- to 150-station range

System 75 — System 75/DEFINITY Communications System Generic 1

System 75 International — AT&T's International private branch exchange offering based on System 75 architecture

System 85 — System 85/DEFINITY Communications System Generic 2

Voice Mail — a system for receiving, storing, and retrieving telephone messages.

life in which changes affect the quality delivered to the customer. The organizations that represented each product felt compelled to examine and improve the existing process. To put the experiences of the organizations in context, we describe the evolution of the design-change procedure in the following key areas:

- Old change procedure and its weaknesses
- Reasons for the new process
- Work and negotiation that took place among various organizations to create a new process
- Implementation, results, and enhancements to the new process
- Future considerations to ensure continued product quality.

The new process has enhanced communication across product lines, reduced product-development intervals, and improved product quality. Other design organizations facing similar challenges may benefit from the techniques we describe in this paper.

The Old Change-Implementation Process

In the past, each development organization used a process with minimal structure to make changes, but each carried out the procedures differently. The procedures used were informal, simple, and internally oriented to the respective electrical and physical development organizations. This process worked when all the customers and suppliers[1] were located near one another and could meet regularly to discuss change implementation. Members of the hardware, laboratory-support, field-support, integration, software, system-test, and manufacturing areas met regularly to exchange ideas and discuss proposed changes.

Before the release of the DEFINITY Communications System product line, this procedure worked reasonably well. Typically, each piece of hardware was used in only one product. If a change were needed, an engineer could make the change, test it in the product, and release it to manufacturing. The simple method used to test and execute those changes precluded the need for a structured process.

System 85 Change Process. System 85 changes were proposed and discussed at biweekly hardware-status meetings and at other meetings. Together, electrical, hardware, software, system-test, laboratory, field-support and manufacturing organizations evaluated how changes would be made and tested.

Changes were introduced to these organizations in a verbal report or a *delta document.* (A delta document presents changes and was created originally to help the electrical-design organization. It described the type of change and its effect from an electrical perspective, and it focused on a small, specific set of customers.) Whenever electrical designers considered a design change important, they would detail the change in a delta document, which then became a reference for future designers changing related designs.

System 75 Change Process. The change-implementation procedure used for System 75 was similar to that used for System 85. It, too, involved regular status meetings, during which the development organization presented reports and reviewed implementation and testing of changes.

The *physical-design letter* was the System 75 counterpart to the delta document. Both attempted to describe and capture changes to electrical specifications and to create a history accessible to others. Both were directed at a limited audience, but they served different customers. As its name implies, the physical-design letter was intended to be used by the physical-design organization, whereas the delta document served the needs of the electrical-design organization.

Weaknesses of the Old Procedures. The change-implementation process used by System 75 and System 85 had numerous weaknesses. It did not focus on customers, and it relied on informal communication and coordination among geographically dispersed organizations. Design changes proposed by organizations other than the design's owner caused a breakdown in existing change-management procedures. Usually, testing could

not be completed on schedule; at times, no testing was performed. Worse, there was no formal method to approve or reject proposed changes, and test results could not alter their implementation.

Often, it was difficult to perform tests completely and thoroughly because change documentation was either incomplete, incorrect, late, or nonexistent. When physical-design engineers conducted a study of 67 physical-design letters, they found only 21 of them useful. Of these, only 4 were complete, 46 were not considered useful, and 6 contained incorrect information. As a result, there was little formal information regarding a change from which to develop tests. The test organizations soon became dissatisfied. Changes to common hardware were being approved without being fully tested in all the products that used it. In a few cases, the new changes created malfunctions that required additional changes and led to excessive product-change costs. At this point, the design organizations recognized that the existing change-management procedures were inadequate.

Old-Process Summary. Prior to common hardware, the old change-implementation procedures provided control, communication, and documentation of changes to their respective organizations. However, these procedures were inadequate for managing common hardware, because they did not address the needs of all user organizations (e.g., manufacturing and other product lines' laboratory support, software, integration, system test, and field-support organizations). But the narrow focus and limited set of customers that each development organization's procedure served were not considered drawbacks before the product lines merged.

Forces Leading to the New Process

Implementing changes became increasingly complex as planning and coordination roles expanded to encompass several products and their design organizations. The transition to common hardware instantly created a new, complex environment consisting of organizations whose contributions came from different locations.

Common hardware is used in more than one product line, and the organizations that design it share ownership with the other product lines. The transition to common hardware was not made without paying a price. This price was the difficulty in simultaneously introducing changes into more than one product line.

The transition to common hardware within AT&T's PBX product lines required design organizations to be more aware of how their changes would affect the products of other organizations. Since there were no established procedures for communicating and controlling changes that affected more than one design organization, it was difficult for these organizations to understand how their changes would affect other design organizations, manufacturing, and the field. It was also difficult for them to document, evaluate, approve, or reject proposed changes. Further, because procedures tended to be unstructured and simple, no formal mechanism existed that allowed design organizations to report their concerns back to the organization proposing the change.

Evaluation Tools and Techniques. The process for implementing changes suffered from such weaknesses as incomplete documentation, insufficient testing, and lack of coordination. The process owners met to discuss how to communicate changes within and between organizations. Using process-quality management and improvement (PQMI) techniques, these process owners listed their suppliers and customers, defined their processes, collected and analyzed data, and identified process-improvement opportunities. (PQMI is a customer-oriented, structured approach to process management and improvement.)

Driving Force for a New Process. Over a six-month period, teams monitored how often product changes were introduced; they found that the occurrences were increasing. From this study, they determined that the documentation and approval processes for implementing changes needed to be improved. During this time, coordination meetings began to dominate management's daily activities. The general consensus was that each

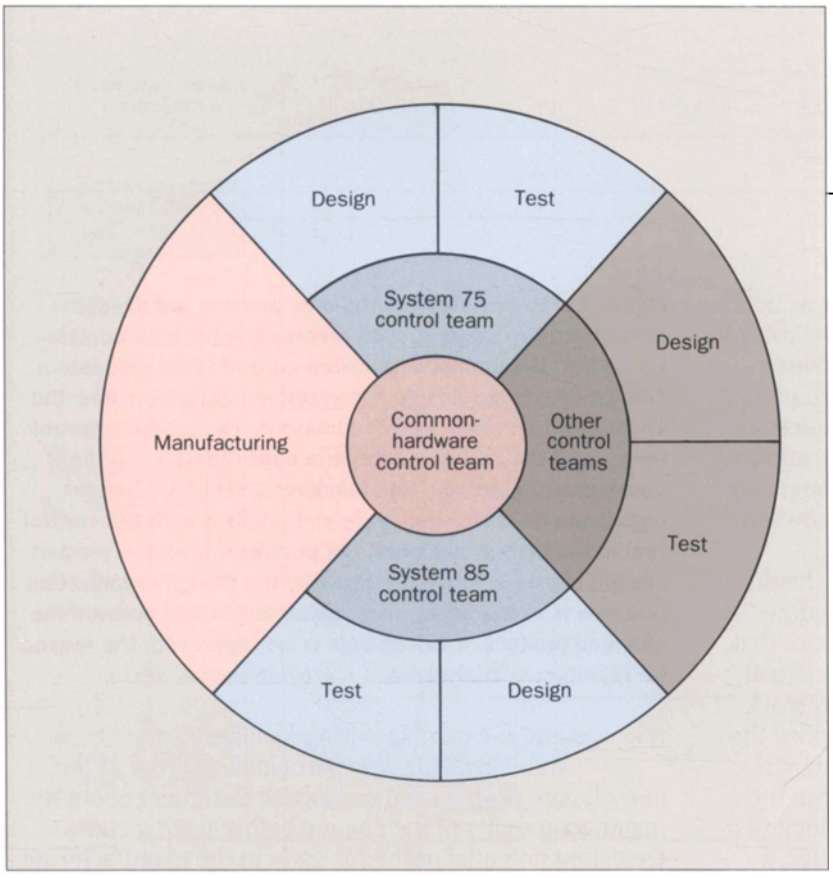


Figure 1. This coordination hierarchy shows the structure of the control teams. The core of the coordination begins with the common-hardware control team. They interact with the next level, which contains the product-control teams and manufacturing. The product-control teams act as the intermediary between the common-hardware control teams and the development organizations (both design and test).

organization's change-management procedures were headed out of control. As more common hardware was developed, tracking the changes became a larger, more complex task. The DEFINITY Communications System projects were reacting to incomplete testing of changes rather than proactively creating solutions. It became obvious to the organizations that represent each product line that the new process had to accommodate changes to any common hardware, regardless of which organization owned the design. The documentation and testing associated with the new process had to be thorough, and all organizations that might be affected by future changes had to approve them prior to introducing them in any of the products.

New-Process Description and Inception

To bring change management back under control and to improve the quality of the DEFINITY Communications System product line, the process owners developed a new process, which incorporated detailed change description by designers, enhanced communication among test organizations, and coordination across product lines. In a systematic way, they identified requirements, defined basic concepts, identified responsibilities, and then created the flow charts and supporting templates for the documents. Detailed planning and negotiation were needed to overcome the differences in methodology, culture, and location of the DEFINITY Communications System's design and development organizations.

High-Level Description. A high-level description conveys the impact and benefits of a new methodology. There are three distinct areas of the new process to consider: hardware and firmware design, testing, and coordination.

Hardware and firmware designers determine how to put the physical and electrical portions of a change into effect; they then document any known implications using a standard template. Test areas evaluate the integrity of the modifications. The coordination area consists of representatives from both test and design organizations, as well as other organizations not as

directly involved in the process. Two control teams coordinate the responsibilities. The *common-hardware control team*, the core of the coordination activity, improves interactions among developers representing each product line. The *product-control teams* manage change activities within their product and provide a communication channel between designers, testers, manufacturing, and the common-hardware control team. Figure 1 shows the hierarchy of this coordination.

The new process contains several steps, beginning with a request for a modification, which is informally discussed among the control teams to ensure that it is beneficial. After designers determine the electrical requirements needed to release the change, they work with the control teams to decide whether to propose the change to other organizations. At this point, designers write documentation that will elicit responses from the other product-development organizations. The documentation consists of a request for approval (RFA) letter, a design-change letter (DCL), and a preliminary engineering-design information document (EDI), which are described later. These documents form a complete package that is distributed to all affected organizations.

The documentation is sent to other organizations so they can begin to evaluate the integrity of the proposed modification. The control teams prepare a schedule and determine which tests will be administered. They do this first at the product level. The product-control teams of products that must test the change then coordinate the testing and approval from their organization. Each organization examines the change to the degree determined appropriate by its control teams. This ensures that all changes are tested in every product to the degree necessary to eliminate field problems and within a time frame acceptable to all participants.

As the change progresses through the testing stages, each organization either approves or rejects it. If the change is rejected, the control teams analyze the reason and determine whether to propose another solution. If the change is approved, the organization officially releases it to the manufacturing location.

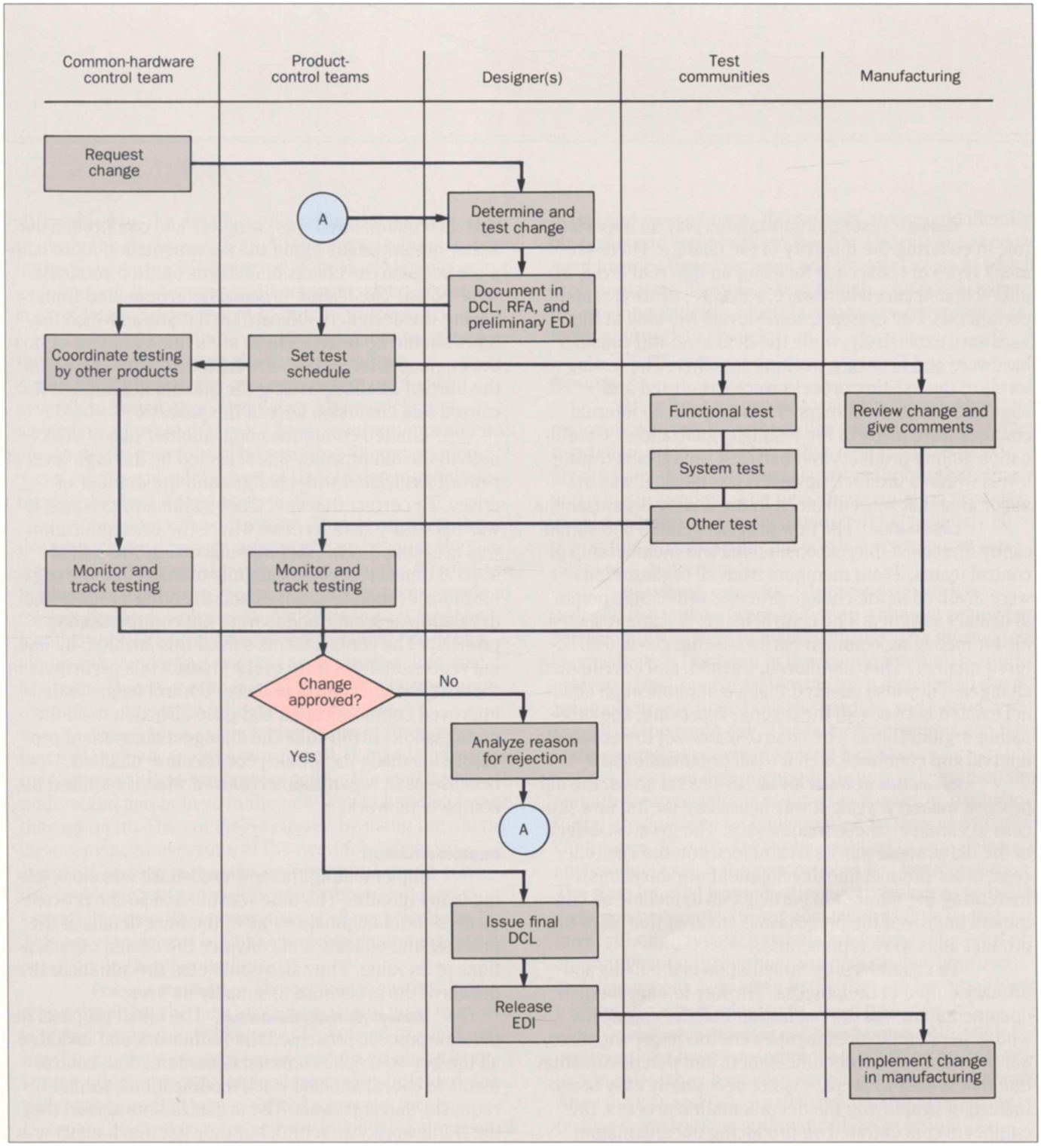
Figure 2. The key steps in the new process are divided among the five major groups responsible for their completion. First, the common-hardware control team requests a change. Next, the design organizations determine how the change will be made and document it. The product-control teams and the common-hardware control team use the documentation to plan and coordinate testing. The test organizations test the change and interact with the control teams to monitor and track the progress. If all the product-control teams approve the change, the design organization releases it to manufacturing, which builds and delivers the changed product. If the change is not approved, the reason for rejection is analyzed and the cycle begins again.

Manufacturing also participates earlier in the new change process and can advise designers about the manufacturability of the change before testing starts. Detecting potential problems early in the manufacturing process avoids the redesign and retesting of changes, thereby saving time and money. Figure 2 depicts the key steps in the new process.

Documentation. Because documentation is the most visible aspect of the new change procedure, the process owners spent considerable time and attention on defining its form. There are five major documents, four of which were new:

- DCL — The main document, which details the reason for change, the change itself, and identifies those who need to approve it.
- *Preliminary* EDI — Gives instructions on how to build a changed product.
- RFA— Requests official approval of the modification from the organizations affected.
- *Approval Letter* — Grants approval to the designers to release the change to manufacturing. These are written by the control teams.
- *Formal* EDI — Releases the change to manufacturing.

Except for the approval letter, all these documents are written by designers.


Common-hardware control team
Product-control teams
Designer(s)
Test communities
Manufacturing
Request change
A
Determine and test change
Document in DCL, RFA, and preliminary EDI
Coordinate testing by other products
Set test schedule
Functional test
System test
Other test
Review change and give comments
Monitor and track testing
Monitor and track testing
Change approved?
No
Yes
Analyze reason for rejection
A
Issue final DCL
Release EDI
Implement change in manufacturing

Testing. Testing organizations play an important role in ensuring the integrity of the change. There are many types of tests, each focusing on different levels of interaction between hardware, software, firmware, and peripherals. For example, some levels will look at the hardware exclusively, while the next level will consider hardware and firmware working together. The testing levels of the existing process were structured and aligned in an efficient manner. As a result, no internal changes were made to the testing organizations. Coordination among products and between the various testing levels within a product, however, was weak; it was the major area that was enhanced in the testing organizations.

Coordination. The new process defined and significantly increased the responsibilities and membership of control teams. Team members from all organizations were involved in the change process, with single points of contact assigned. The control teams became responsible for managing common-hardware changes in a structured manner. They monitored, tracked, and coordinated changes. They also ensured that a communication channel existed between all the testing, approving, and originating organizations. The control teams set the approval interval and communicated it to all organizations.

Resolution of Weak Areas. In several areas, the old process was very weak; it was necessary for the new process to eliminate these weaknesses. The greatest defect of the old process was its lack of focus on the customer (e.g., other product-line development organizations). Increasing the number of participants to include all customers improved the process and ensured that all of the product lines were represented.

To customers, documentation is the focus and primary output of the process. The key to improving documentation was the realization that the engineers who generated the documents were the major suppliers, not the users, of the documentation, and that documentation that is easy to prepare is not necessarily easy to use. Instead of simplifying the documentation process, the engineers concentrated on producing documentation that the customer felt was complete and comprehensive. Other organizations found the documentation more complete because the effects of changes on their products were noted. The testing organizations benefited from having the designers indicate such items as which features should be tested. These are a few examples of how the engineers focused on the customer. This increased the burden on those writing the documentation, but it caused less confusion later in the process.

Limited communication, another major weakness in the old process, was reflected by the high level of rework associated with changes and the number of crises. To correct this deficiency in the new process, it was necessary to determine where the communication was breaking down. After manufacturing was halted several times, it became painfully obvious that the organizations designing changes and the other product-line development organizations were not communicating properly. The control teams solved this problem by having representatives from every product line participate in the new change-control process. Control teams both improved communication and gave direction to all the organizations involved in the change-management process. This made the whole process more efficient, because each organization received what it required to complete its work.

Implementation

Implementing the new procedure was slow, taking many months. The time was needed so the process owners could negotiate some of the finer details of the process, and educate and convince the design organizations of its value. They also completed the administrative details of the procedure to simplify its use.

Immediate Implementation. The initial proposal for the new process presented the framework and included all the key concepts: common documentation, control teams to coordinate and track modifications, formal requests, and approvals. The organizations agreed that the framework was sound, but they felt much effort was

still needed on the details surrounding the concepts, particularly the documentation. All the organizations involved in the change process accepted the control-team concept as proposed. It was easy to incorporate, since informal control teams were present in the old process.

After many hours of negotiation between customers and suppliers from the various product-development teams, the process owners produced several documentation templates. The participants agreed on a format that met all the requirements and was acceptable to everyone. The resulting documentation was a "synthesis" of the best of the old documentation used by System 75 and System 85.

Education. The education effort focused on the design and development organizations, because they were the most affected by the enhancements. The education was varied. Large group presentations were made to explain the basic enhancements, their impact, and the justification. The process owners explained the details, along with supporting references, in smaller, informal sessions. They sometimes held these smaller meetings one on one, in part to influence the skeptics.

Gaining buy-in. Convincing users of the importance of the new process was critical. A mandate by upper management alone was unacceptable; the staff had to understand and believe in the new way to handle change management. The confusion caused by using the old process convinced everyone of the need for a new procedure. Consensus that the new proposal would solve the problems was more difficult to obtain, but it was essential to gain the cooperation of all organizations. This agreement was built by involving customers and suppliers in the negotiations.

Process Flexibility. The organizations involved recognized that the new procedure would need to evolve as their requirements changed. They tried to avoid making the change-management procedure an obstacle as surrounding processes and subprocesses unfolded. Initially, each product was assigned a process owner. Because the owners were actively involved in the control teams and were close to the process, they could identify obstacles and remove them quickly. Users were encouraged to voice their concerns and pinpoint areas in which problems were likely to occur. Finally, the process owners working with the control teams were empowered to make appropriate changes.

Results

After the new process was introduced, change management was brought under control. Improved documentation, such as the DCLs, has resulted in reduced product-development intervals, more thorough testing, and a better product. The new documentation provides consistent information and enough detail to satisfy all users; this is reflected in the positive response of suppliers and customers.

Quantitative Results. The new process has reduced the time between initiating a change request and releasing the change to manufacturing. The most significant reduction has been in the testing interval. In high-priority cases, the control teams have distributed the DCL using electronic mail, built the models, and begun testing, all on the same day. The test organizations can begin testing simultaneously in several locations.

Because documentation is now delivered on time and other organizations respond to it quickly, manufacturing changes can be implemented faster and with more confidence. Manufacturing has not had to stop delivering any products since the new process has been in place. The time interval from identifying a problem to releasing a change in manufacturing now takes as little as five days, although typical intervals are longer. The level of communication throughout the process has improved, and discussions held early in the process have produced a higher-quality product with fewer revisions.

Simplified Planning and Coordination. Although the organizations have expanded their planning and coordination roles, they have also simplified them enormously. After the RFA and DCL are distributed, the appropriate testing organizations automatically take action. The

control teams set the interval for approval after considering the urgency of the change and the testing required. The control teams also review the approval interval before it is established and convene weekly to evaluate progress toward meeting the approval date. The combination of an approval interval and improved coordination has eliminated many problems inherent in the old process.

In the past, the designer was responsible for ensuring that the changes were tested to the degree necessary for their applications. An advantage of the new process is that the control teams relay information about changes to the other design organizations, who in turn decide on the level of testing they require. This helps product teams identify potential problems earlier in the process. Most problems are now uncovered in the lab, not in the field.

Improved Testing. The DCL describes to the test organizations all that is known about a change so they, in turn, can determine which tests to conduct. The solved problems and recommended testing scenarios are detailed in the DCL; unsolved problems are also included to alert the test organizations of potential test-case failures.

The DCL has become such a valued part of the change-management process that testing will not begin until one is available. Now, when problems are uncovered during testing, a clear communication path exists to the developer and the other organizations.

Communication Tools. Implementing the change-management process requires that control teams track the DCLs across products as well as their internal progress within a product. The design organizations have found that the most effective way to communicate design changes is to have the common-hardware control teams and the product-control teams track the DCLs. Currently, all DCLs active on any project are discussed weekly in common-hardware control-team meetings. DCLs are also tracked internally by product-control teams, who regularly report the status and any required actions, such as testing, to the affected organizations.

To track DCLs effectively across projects, the common-hardware control team established a database containing all DCLs. The information in this database has served as the meeting notes of the common-hardware control team. As changes are completed, they are marked "inactive" in the database and are used for historical purposes and metrics. The database flags problems discovered during testing and alerts the organizations involved. If problems necessitate additional changes, other organizations stop testing until a new DCL is written. This has allowed the testing organizations to conserve resources and to become more efficient.

Enhancing the Process

The process described in this paper is ongoing and has been subject to revisions and enhancements. As the need arises, the process owners revise sections of the DCL and RFA and update the templates. Standard templates enable users to maintain consistent documentation throughout the process.

PQMI. Through PQMI, design organizations continue to refine the current process and learn more about customer requirements. Results show that the new change-management process is being used as expected, has improved over time, and that customer requirements are being satisfied. The process owners will continue to address deficiencies and new requirements on a continuing basis.

Effect on Other Processes. The new process has worked well enough to encourage similar activities in other areas of the DEFINITY Communications System development organizations. Using PQMI techniques, these organizations are reviewing nearly all their processes to learn more about their customers' needs and to improve the processes.

Conclusion

The organizations that developed the DEFINITY Communications System replaced an inefficient change-management process with one that provides more effective communication and implementation of changes to common hardware in all the product lines. The process owners identified requirements by applying the

customer-supplier model, and then evaluated and reshaped the process to manage design changes more effectively. The product-development organizations now have a better communication path among all the organizations involved in the design and manufacture of the various product lines, both within and across products. Placing high emphasis on customer requirements has increased both the customers' and suppliers' satisfaction. This emphasis also has reduced product-development intervals and improved the quality of their products.

Reference

1. E. M. Sieli, "Managing a Project as a Process," *AT&T Technical Journal*, Vol. 70, No. 2, March/April 1991, pp. 33–39.

Biographies (continued)

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