Requirements for a Brain Transplant for the New 1B Processor

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Generating the system requirements for the 1B processor, the new "brain" of the 4ESS™ switch, was a critical step in the front-end process. The set of requirements, prepared by cross-functional teams, was used both to specify hardware and software development and to guide verification. To shorten the overall cycle time, the production of these specifications also overlapped the hardware and software development processes. This paper describes the customer-supplier interaction model used, the approach chosen to facilitate productivity during requirements production, a high-level perspective of the requirements, the process used to generate these requirements, the challenges encountered, and the teamwork solutions via process optimization that helped make this project a success.

Introduction

The 1B processor requirements for a "brain transplant" of the 4ESS™ switch are based on the customer-supplier model in which the customer has a business need and the supplier—in this case the development organization—provides a product to meet that need. Both the customer and development work closely together to agree on the project schedule, quality requirements, and a cost-effective product. The term "requirements" used here refers to the specifications of the central processor upgrade, or a customer-supplier "contract," which describes the product that the customer can expect and that development will deliver.

1B Customers. There were a variety of customers for the processor upgrade. The primary customers are the Communications Services Group (CSG) of AT&T, and local exchange carriers that own 4ESS switches. Each of these customers consists of many stakeholders, representing multiple disciplines in the planning, development, and deployment of telecommunications capabilities and services. Examples of the major customer stakeholders and their responsibilities in the 1B project are discussed below.

Feature Sponsor. The feature sponsor represents and speaks for the customer as a whole. In the event that the stakeholders are dead-locked on an issue, the feature sponsor has the final decision.

Switch Systems Engineers. Systems engineers own and run the front-end process that generates requirements. They also author and own the requirements documents. Systems engineers are responsible for coordinating the activities of all the participants in the front-end process, and for insuring the comprehensiveness of—and consistency among—the related requirements documents. For the 1B project, 4ESS systems engineers made sure that the requirements identified the specific customer needs for the processor upgrade.

Acceptance Test Engineers. The customer will accept the product only after rigorous acceptance testing, performed according to an acceptance test plan based on the system requirements. In order to ensure that all the essential test needs are included in the requirements, these test engineers must be involved in the preparation of the system requirements as part of the requirements teams.

Installation and Retrofit Personnel. The customer requested that the new 1B processor be installed in live 4ESS offices, without

Table I. Examples of Requirements Prepared for the 1B Processor

Requirements type	Functional area	Requirements document
Base requirements	Processor upgrade	4ESS™ switch processor upgrade Feature specification document (FSD)
Specific requirements	User interface	Maintenance control complex interface specification
	Lab and field tool	1B processor utility system requirements
	Installation and retrofit	4ESS switch processor retrofit requirements
Additional requirements	Operations planning	1B processor operations technical plan
	Memory expansion	1B processor memory store expansion
	Memory backup	1B processor memory and file store backup

causing any unplanned system outages. This required a combination of installation- and retrofit-related product specifications and special office pre-conditioning measures to be prepared. The personnel who designed these specifications and measures were part of the 1B processor requirements team. They made sure that the installation- and retrofit-related product specifications were included in the requirements.

Network Operations Personnel. Ongoing operation, maintenance, and provisioning of the 4ESS switch inevitably would be affected by replacing the switch's central processor. Thus, personnel responsible for systems engineering of network operations, and for carrying out operations activities, were part of the requirements teams to ensure that these issues were addressed.

Development (Supplier). AT&T's Network Systems Group (NSG) is the supplier of the 1B processor. Within the development effort, there are many stakeholders, reflecting the multi-disciplined nature of the design, development, and manufacture of the equipment. Examples of the major development stakeholders and their responsibilities in the 1B project are discussed briefly below.

Hardware Designers. Hardware designers are responsible for the design and development of new hardware equipment and for making the necessary hardware changes to conform to the requirements, not only in the processor itself, but in related subsystems of the 4ESS switch.

Software Designers. Software designers are responsible for the many new software developments and changes to conform to the requirements.

System Test Engineers. System test engineers perform system integrity and performance verification testing of the product against the requirements. These tests are done in both the AT&T NSG test labs and in the AT&T CSG integrated test lab, where regression tests are also part of the overall system testing.

Factory Test Personnel. Factory testers use the actual switch generic software to test the newly manufactured 1B processor. This generic software is provided by the development organization and loaded into the 1B processor and switch file systems. Just like a field office, the factory receives generic updates when they are released.

Panel 1. Abbreviations, Acronyms, and Terms

CSG — Communications Services Group
FSD — feature specification document
ID — identification
IDR — implementation decision record
MCC — master control complex
NSG — Network Systems Group
PPI — processor peripheral interface

The next section of this paper, "Approaches for Productivity," describes the approaches chosen to facilitate productivity. The section "Overview of Processor Requirements" gives a high-level perspective of the requirements for the 1B processor. The section "Requirements Front-End Process" provides an overview of the requirements generation process, and the final section, "Requirements Process Optimization," focuses on the process optimizations implemented for the 1B project.

Approaches for Productivity

One of the first challenges of the 1B project was the sheer size of the undertaking. Requirements were needed in diverse areas, such as internal processor functions, user interfaces, and installation procedures. It was recognized early on that it would be difficult and perhaps inefficient for a single set of people to focus on the complete set of requirements. After some deliberation and negotiations with the customers and the development organization, an approach was adopted that requires multiple requirements documents to be prepared by parallel teams, with each team focusing on a specific segment of the requirements (See Table I).

Processor Requirements. Four requirements documents were prepared to cover the processor upgrade.

Table II. Comparison of 1A and 1B Processor Capabilities

Attribute	1A processor	1B processor
Central control clock	1.43 MHz	6 MHz
Peak call processing capacity	650K busy hour call attempts (BHCA)	1.4M busy hour call attempts (BHCA)
Memory access time	1 clock cycle	1 clock cycle
Program store (PS)	2M words	2M words
PS expansion	None	To 3M words
Call store (CS)	2M words	5M words
CS expansion	To 3.75M words	To 20M words
PS/CS word size	24-bit data	32-bit data
PS/CS address expansion	23 bits	30 bits
PS/CS addressable memory	8M words	1G words
Future bus expansion capacity	None	24 32-bit clients
Maintenance control complex	Hardware panel	Color CRT
Field utility system	Utility program	Embedded utility processor and utility program
Switch downtime objective	Less than 3 minutes/year	Less than 3 minutes/year
Equipment cabinets	5 open frames	2 cabinets with doors
Cabinet cooling	Convection air	Forced air
Office environment	Compliant with network equipment building system (NEBS)	Compliant with network equipment building system (NEBS)

These requirements documents are:

Processor Upgrade Specifications. This document provides the base requirements for replacing the 1A processor with the 1B processor. It covers requirements for processor real-time memory increase and expansion, reliability and performance, physical design, operations and maintenance, fault detection, and recovery. Future switch evolution also is considered here.

MCC Interface Specifications. This document specifies the maintenance control and display of the 1B processor. These functions are carried out through the master control complex (MCC), which includes parts of the 1B processor video-display terminal support and remote maintenance. The MCC replaces the 1A processor peripheral interface (PPI), the 1A electromechanical panel master control console, and its E2A telemetry system. The same control and display functions are provided to personnel at the switch location, and to a remote site such as the technical support center in the network. Multiple MCC links are needed to achieve maximum reliability and flexibility.

Utility System Requirements. This document provides requirements for a 1B utility system that can be used in the switch development and test lab, factory, installation and retrofit offices, and in the field as a maintenance and debugging tool. The utility system, interfaced to a high-speed Ethernet link, provides the utility functions to personnel at the switch location, and to remote personnel at the technical support center in the network.

Processor Retrofit Requirements. This document defines the requirements for the 1B processor retrofit to the 4ESS switch. It provides a method for the new processor to be introduced into live offices without incurring any unplanned system downtime.

Other Planning and Requirements Documents. Multiple planning and requirements documents, in terms of network operations and memory expansion, were prepared for the 1B processor. Chief among these documents are the following:

Operations Technical Plan. This document defines the planning of operations support systems required for operations and maintenance of the 1B processor in the network.

Memory Expansion. The 1B processor program store and call-store expansions are part of the processor upgrade. These requirements defined the increase in memory capacity that meets both the present and future needs for memory expansion.

Memory Backup. This document provides requirements for a method to back up the switch memory. The requirements cover the memory of both 1B processor store and 3B20D file store.

Overview of Processor Requirements

In order to perform a flawless "brain transplant," a comprehensive and unambiguous set of requirements was essential to describe the set of customer needs. This section gives an overview of the requirements themselves, as related to the set of high-level AT&T network needs.

As the brain of the 4ESS switch, the 1B processor must meet a variety of high-level AT&T network needs.[1] These network needs and, hence, the corresponding requirements, fall into several categories:

- Preservation of the embedded base,
- Maintenance of existing interfaces,
- Very high reliability,
- Non-disruptive retrofit and deployment,
- Minimization of dual feature development and testing,
- Adequate memory and a real-time increase for future evolution, and
- Interface bus.

Table II compares the 1B processor capabilities to the 1A processor and provides a sampling of the requirements for the 1B processor. These requirements are described below.

Preservation of the Embedded Base. From a requirements perspective, preserving the existing switch base led to an architecture and coordinated requirements that used the existing 4ESS switch hardware and application software. Requirements were specified to ensure a seamless and transparent use of the existing base, providing a significant cost savings.

Maintenance of Existing Interfaces. Requirements specifying the maintenance of existing operations interfaces were jointly specified through a section on the operations support systems interface in the switch requirements, and through more detailed specifications in the operations technical plan. And although in most cases the physical interfaces to operations support systems did not change, appropriate specifications had to be provided to accommodate a variety of new data.

Very High Reliability. The 1B processor needed to maintain the very high reliability of the AT&T network. Thus, this new "brain transplant" had to meet the expected switch downtime objective of less than three minutes per year. To support the reliability objectives, performance and reliability requirements were written and switch maintenance and operations requirements were specified. Significant modeling efforts and environmental stress testing were used to achieve an early "sanity check" on the requirements.

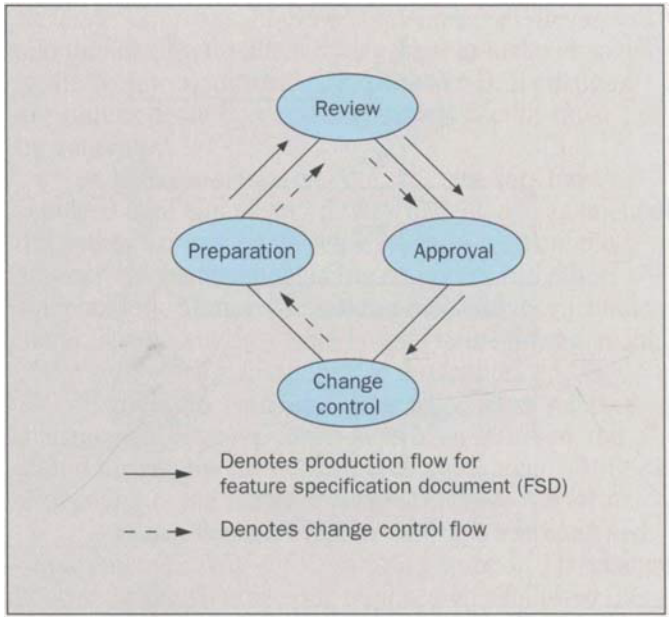


Figure 1. The feature specification document (FSD) production process consists of three major tasks: requirements preparation, review, and approval. Change control is imposed to record any subsequent additions, corrections, or deletions to the requirements.

Non-Disruptive Retrofit and Deployment. It was essential that the 1B processor replacement procedures did not disrupt customer service, either during the retrofit of each processor "brain," or at any time during the entire deployment. This was achieved through a "hot-slide" of a new processor into an office, without causing any unplanned system downtime. An entire requirements document was devoted to this retrofit process, and detailed procedures were written to support it. In addition, special hardware was produced to allow this retrofit process to proceed expeditiously.

Minimizing Dual Feature Development, Testing. The minimization of dual feature development and testing was

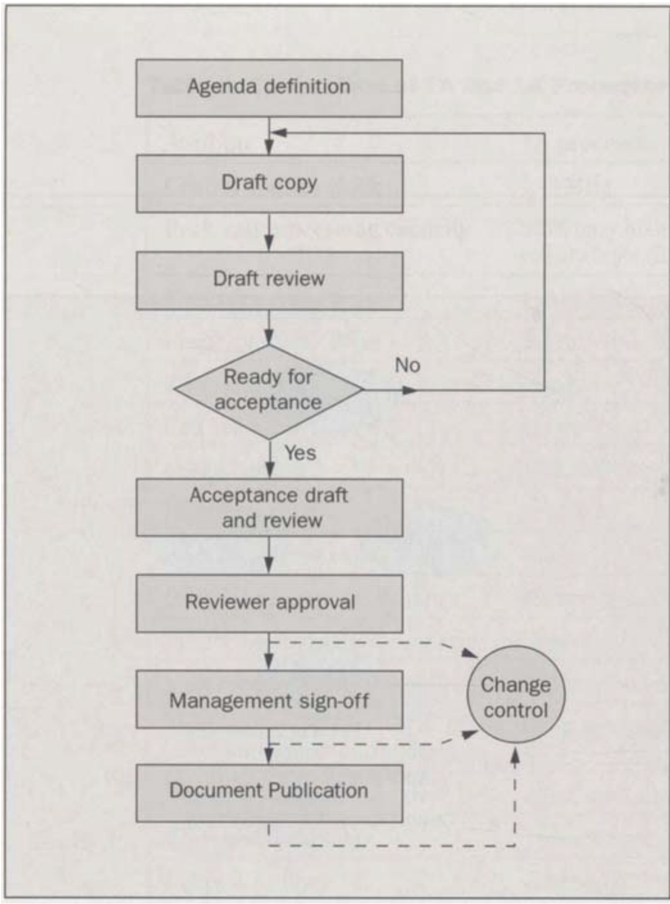


Figure 2. The production of the 1B processor requirements followed the seven steps of the feature specification document (FSD) production process. The last three steps are under change control.

primarily a function of transition planning and deployment, ensuring that overall deployment could be accomplished in about one year. This minimization avoided the additional costs associated with dual development and testing. Requirements were specified to support this transition and the whole retrofit process, as previously discussed.

Memory Requirements. The memory requirements were covered in separate memory expansion and backup requirements documents. These requirements ensured that adequate memory was added for both program and call data storage. Adequate real-time increases in the future were ensured via requirements for expanding the processor capacity.

Interface Bus. For future growth and evolution, a high-speed bus was developed for the 1B processor. This interface bus supports transactions between 1B memory and clients on the bus, and between bus clients, using a 30-bit address and 32-bit data paths. The bus can accommodate a total of 24 clients, and is the path for evolving the switch processing platform.[2]

Requirements Front-End Process

Project requirements are contained in a feature specification document (FSD), which provides a specific description of what the system must provide for a given capability or service. An FSD should specify *what* function must be performed but not *how* that function should be implemented—unless this is required to meet a specific interface with other systems. The steps that lead to FSD production are called the requirements front-end process,[3] and its quality is an important determinant of the product's quality.

The requirements front-end process covers the FSD production and requirements change-control processes (see Figure 1). The FSD production process consists of three major tasks:

- Requirements preparation,
- Requirements review, and
- Requirements approval.

To prepare for an FSD, multiple drafts are produced. Each draft is reviewed by both customer and development representatives to ensure that all the requirements identified for the capability or service are covered. After the FSD is complete, it will be put under change control.

The change-control process provides a feedback loop in the requirements front-end process to re-visit the requirements of a completed FSD. When changes to the requirements are needed, a modification request (MR) will be issued to start the change-control process. Change control ensures that the completed FSD is always kept updated throughout the development and deployment cycles of the product.

FSD Production. The production of the 1B processor requirements followed the seven steps of the FSD production process (see Figure 2). The seven steps are described briefly below.

Agenda Definition. All participants in the FSD process must agree on which FSDs are to be written, and the participating organizations must make specific staff and schedule commitments to support the approval process. This places obligations on systems engineering, the appropriate development organizations, and other stakeholders of the project.

Draft Copy. An FSD could be written by one or more authors, and each draft copy of the FSD is intended to address all necessary issues of the feature. The

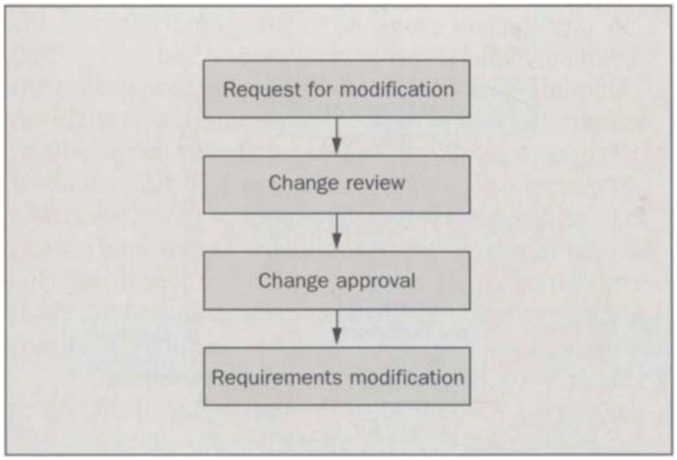


Figure 3. Change control is a streamlined requirements change process. The change control for the 1B processor requirements followed the four steps of an overall change process—the request for modification; a change review by stakeholders; change approval; and, if approved, modification of the requirement.

author must make all necessary changes to the FSD that users identified from the draft review.

Draft Review. It is expected that all FSDs will be reviewed thoroughly outside the author's organization. The intent of the draft review is to provide the author and reviewers with a consistent way of determining how close the FSD is to acceptance. If the result of the review calls for re-review, then the reviewers evaluate whether the document has progressed adequately to be reviewed for acceptance. The acceptance review is held only when all major draft issues have been closed.

Acceptance Draft and Review. An acceptance draft is produced when all major issues have been resolved or when there is a plan for resolving major open issues. The purpose of the acceptance draft is to satisfy all reviewers that the issues have been resolved properly, and that the FSD meets the standards of quality necessary for publication—that is, accuracy, completeness, clarity, and conciseness.

Reviewer Approval. After agreement has been reached that the FSD is ready for publication, a reviewer approval form and a copy of the FSD, marked with changes from the acceptance review, is sent to the reviewers. Reviewer approval should be unconditional. Reviewers should not sign the form if they want to make changes to the reviewer approval copy of the FSD. If changes are required, another reviewer approval copy must be generated.

Management Sign-Off. After all reviewers have returned their signed approval forms, the management of the author's organization requests approval from the appropriate management of the reviewers and other stakeholders. Management sign-off should be unconditional. The approvals should be sent to the management of the author's organization or to the author.

Document Publication. After all necessary signed management approval forms have been returned, the author distributes the document as appropriate, along with copies of the signed management approval forms.

Change Control. Change control is a streamlined requirements change process (see Figure 3). The change control for the 1B processor requirements followed the four steps of an overall change process. Each of these four steps is described briefly below:

Request for Modification. A request for a requirements addition, deletion, or change to an FSD is sent to the FSD author and others involved in the process. The FSD author or the owner of the document reviews the MR with the originator. If the request is pursued, a severity, or priority, rating is assigned to the MR.

Change Review. The modification originator, the owner of the FSD, and the stakeholders of the changes review the request, and decide to accept the MR or defer it for further study.

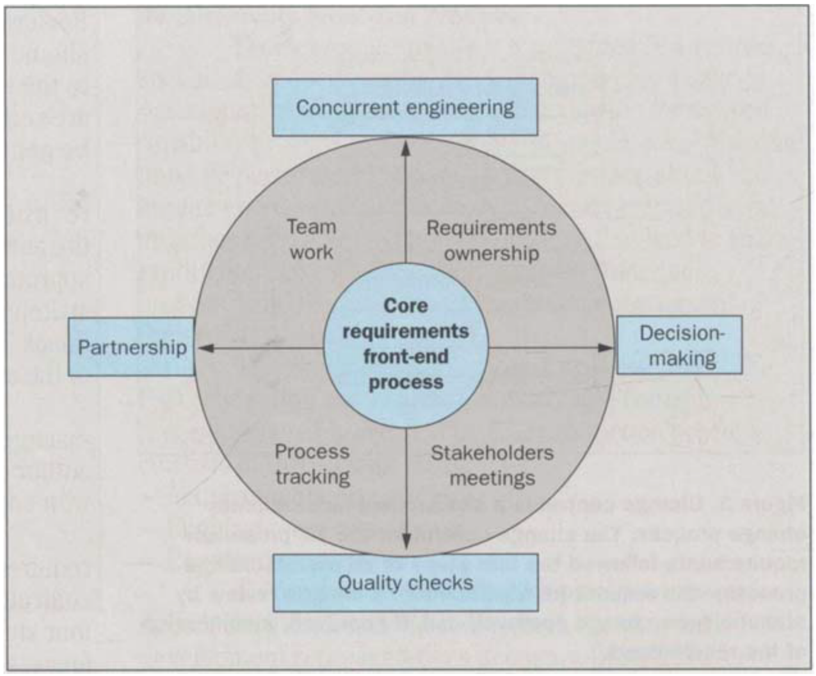
Change Approval. After the changes are agreed to, the approval is sent to all stakeholders. The approval of the changes by customers and development organizations is mandatory.

Requirements Modification. After all the necessary approvals have been returned, the changes are official and they are made to the FSD. The original MR can then be closed.

Requirements Process Optimization

Special care was devoted to requirements generation to ensure that the 1B processor would be a robust and highly reliable processor of the 4ESS switch beyond the year 2000. The FSD front-end process is intended to capture all the essential product requirements. To optimize

Figure 4. To optimize the generation of the 1B processor requirements, enhancements to the existing feature specification document (FSD) front-end process have been implemented—not only for the 1B processor, but also for the evolution of the switch platform. These enhancements are described as partnership, including improved teamwork techniques; concurrent engineering, including requirements ownership; improved decision making, including stakeholders' meetings; and quality checks, including process tracking.



the generation of the 1B processor requirements, enhancements to the existing FSD front-end process have been implemented—not only for the 1B processor, but also for the evolution of the switch platform. Chief among these enhancements are the following (see also Figure 4):

Enhancing Partnering. The discussion of this enhancement includes the need for communication among all parties, the need for a close working relationship between systems engineering and development, and the need for cross-functional interfaces.

Communication. The customers need a way to communicate changes in their needs to development, and development needs a way to voice its concerns to the customers. To meet these needs, a working partnership comprising the customer, systems engineering, and development representatives must be formed. For the 1B processor, most processor-related meetings—such as customer needs definition, requirements generation and review, testing, installation, and retrofit—contained representatives of all the partners. This facilitated teamwork and ensured that issues from all areas were addressed.

Systems Engineering/Development Team. One of the keys in this requirements effort was a very close working relationship between the systems engineering and development communities, fostered, in part, by the simultaneous production of the system requirements document and a development architecture document. Because of this close working relationship, misalignments could be quickly identified early in the process. In addition, systems engineering was integrated into the overall development project plan, and included in the development project status meetings. And to ensure requirements responsibility throughout the development process, a development manager was assigned to "own" each requirement and ensure its proper implementation.

Cross Functionality. Even though the entire requirements effort for a large and complex project can be broken up by functional areas, the project would not have been successful if the teams worked in isolation. Thus, formal interfaces must be developed between and among the functional requirements teams. At the very least, each team must be represented at the various document reviews for the other teams. In most cases, each team should be represented at the working meetings for the other teams. Employing this technique, cross-dependencies can be identified at a very early point and rework will be minimized.

Enhancing Concurrent Engineering. The discussion of this enhancement describes how requirements production was made more manageable, the advantages of concurrent effort, and the importance of requirements tagging and ownership.

Division of Requirements. In order to make the requirements writing effort more manageable, the job can be divided into smaller and more manageable pieces. For the 1B processor, these divisions included the overall processor upgrade requirements, human interface specifications, utility system function requirements, switch retrofit requirements, and the operations technical plan. The use of several smaller documents allows each area to simultaneously form requirements teams consisting of only those parties involved with the specific division. These teams could then identify, investigate, and resolve issues, and operate on independent, parallel schedules.

Concurrent Effort. The reduction of cycle time for a project of the magnitude of the 1B processor was vital. The processor was critical for the network to meet new and growing capacity demands and to provide a switch evolution path. One method that can be employed to achieve this end is concurrent effort. For the 1B project, it consisted of executing several facets of the project in parallel. There were periods in the project when requirements, hardware and software development, and verification testing were being conducted in parallel. In addition to reducing cycle time, other benefits can be realized. For example, changes in customer needs could be fed directly into the development process, and technical road blocks could be communicated to the customer, often resulting in a requirements change in a short turn-around time.

Requirements Tagging. As cited above, system requirements can be broadly divided and prepared by the various requirements teams. However, even within a single document, a wide diversity of requirements exists. For example, a base system FSD would contain requirements on hardware, audits, fault recovery, and many other functions. If these requirements were simply lumped together, there would have been a high probability that there would be redundant work, capabilities would be missed and not developed, and rework would be required. To prevent this from happening, a tag ID was added to each requirement to identify the impacted area and to point out each area that would have to test and prove compliance.

Requirement Ownership. If only requirement tag IDs are used to indicate impacted areas without additional follow-up, the responsibility for the requirements still will be unclear. To solve this, each requirement—its development and ensured compliance—must be assigned an owner. For example, an individual supervisor could be responsible for follow-up of any issues pertaining to the requirement. This ownership proved to be invaluable during the FSD front-end process, as a method to very quickly route questions to the appropriate persons and to work technical inconsistencies.

Enhancing Decision-Making. This section discusses some steps taken to improve the decision-making process.

Resolution of Critical Issues. The production of requirements for a large project like the 1B processor involves numerous decisions and negotiations between the major stakeholders. To accomplish the goal of expeditiously making decisions, a series of "stakeholders' meetings" was held throughout the requirements production cycle. The intent of these meetings was to provide a forum for project issues to be discussed and for consensus to be reached.

Stakeholder Identification and Empowerment. All the major project stakeholders should be present at each meeting and must be empowered to make decisions. To do so, the stakeholder representatives must consist of the appropriate levels of management that can make these decisions.

For the 1B project, the representatives attending the stakeholders' meetings included the feature sponsor representing the customers, the systems engineers authoring the requirements, and representatives of both the development and deployment organizations. The development representatives included both those developers directly involved with the issue under consideration, and those involved with project management, product testing, office installation, and field support. The deployment representatives included such areas as overall customer product deployment planning, product documentation and training, and customer product support. The early involvement of post-development stakeholders, such as manufacturing and maintenance, added significantly to the quality of the decisions made.

Identification of Issues. The stakeholders meetings were intended to address only critical or controversial issues for the project. The large number of everyday issues should be investigated and resolved by various requirements subteams. To identify the critical issues for the 1B stakeholders' meetings, a filtering team was formed, consisting of a systems engineering representative and a development representative. They met periodically to identify issues that were significant enough to be addressed at the next stakeholders' meeting.

Issue Investigation and Resolution. After each critical issue was identified, a systems engineering owner was assigned to it. The owner is responsible for gathering the appropriate individuals who are knowledgeable and involved in each issue, and formulating a series of alternative directions for each issue. The owner is also responsible for investigating alternatives, documenting the advantages and disadvantages of each option, and formulating a recommended course of action prior to the meeting, if possible. At the designated stakeholder meeting, the owner would then present the issue, any alternatives, and any recommended actions. After the discussion, either a decision is made, or the owner would be assigned follow-up items for the next meeting.

Documentation of Issue Resolution. The decision made on each issue should be documented in meeting notes after the meeting. This follow-up is essential, so that a record of project decisions exists on these critical issues, as well as the reasoning that led to the decision. In case of any subsequent changes in the assumptions leading to the previous decisions, or changes in customer needs, these records could be consulted and a new analysis could be easily constructed.

Enhancing Quality Checks. This section briefly describes several quality checks used to manage and track issues.

Requirements Management. Since the requirements for a large and complex project cover many functional areas, a global perspective is necessary to manage the production activity. This global monitoring of the requirements effort can be achieved by naming one of the responsible systems engineering supervisors as the requirements focal point throughout the requirements production effort. As part of this function, decisions should be made on how the requirements are tracked and how the systems engineering job could be more doable in the short time frame.

Global Progress/Issue Tracking. To ensure appropriate progress, checks must be made periodically against requirements milestones, and major issues and their resolution must be tracked. For the 1B project, this progress and issue information was presented at a variety of management status meetings to provide a global view, and also was used as part of the overall project tracking.

Implementation Decision Record. For a large and complex project, it is often difficult to completely satisfy all requirements in the same release. In some instances, the customer also would want to go on record with various requirements targeted for a later release. The implementation decision record (IDR) can be used to address these two issues. The IDR is additional text appended to the enumerated requirements indicating the agreed upon compliance to each requirement and a target date for compliance. During the development and deployment cycles, all the implementation decsions will be checked and recorded.

Conclusions

The generation of the system requirements for the 1B processor was a critical step in the front-end process. The set of requirements produced for the project served as a contract between customers and development organizations, and as guidelines for the verification of a flawless "brain transplant" for all 4ESS switch offices.

The specifications prepared for the 1B project followed the FSD front-end process, optimized to reduce the overall project interval. This front-end process provided the basis to generate system requirements in an orderly, systematic manner. On the other hand, process optimization in the areas of partnership, concurrent engineering, decision-making, and quality checks played a critical role to meet the challenges of tight schedules, high performance, and organizational barriers. Together, they helped make the 1B project a success and set an example for the future evolution of the switch platform.

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