Total Quality Management for a Large Software Project

Joseph S. Colson, Jr.
Edward M. Preil

The 5ESS® switch project faces a challenge increasingly common to many industries—how to simultaneously improve quality, shorten the interval between product development and delivery, reduce costs, and increase revenues. Over the past several years, we have realized that we must design and manage our development process with the same rigor and effort that we currently design and manage our products. This paper summarizes the approach, current status, and some early results of our efforts to conceptualize, design, and achieve a quality management system for the international and U. S. 5ESS switch projects.

Introduction

The 5ESS switch was designed and developed by AT&T as a universal digital exchange to meet the needs of telecommunication administrations making the transition from analog to digital exchanges in local, transit (local-toll), trunk, and international (gateway) applications. The first 5ESS switch went into service in 1982. Today, over 40 million subscriber lines are supported on 5ESS switches in service worldwide.

The continued success of the 5ESS switch project is dominated by the need to produce large software products (more than 300,000 source lines), built on an ever-growing software base (more than 4 million source lines), interspersed with frequent, smaller software products. These, in turn, all have stringent functional, response time, and reliability constraints. Project management traditionally spearheaded this effort by working with the development community to formulate and track large, complex plans that included thousands of milestones. An adaptation of the standard "waterfall" methodology (specify, design, code, test, and release—theoretically in sequence) for software development provided the template for most of this project management activity.

As the switching business becomes more dynamic and competitive, the traditional project management approach alone cannot keep pace with both the complexities of large-scale software development and the growing number of customers with diverse and rapidly changing needs. There is a growing demand to produce defect-free features in less time and at lower cost. This demand can only be met by expanding the management system to include managing and improving not only the products being developed, but the development process itself.

This paper explores the challenges and outcomes encountered in developing a process management and improvement system, and in integrating that system with existing project management to create an evolving total quality management system for the 5ESS switch project.

Total Quality Management

Total quality management (TQM) is not a new concept. (See Panel 1 for definitions of abbreviations and acronyms.) Also known as united total quality control or strategic management quality control,[1] it has been used successfully by many Japanese companies and is gaining support in the United States. Conceptually, TQM is an integrated management approach designed to transform customer needs and requirements into customer satisfaction and business success. TQM emphasizes the continual management and improvement of all work and business processes to meet both short-term and long-term customer needs. The fundamental

elements of TQM are:

- Strategic quality planning
- Quality in daily work
- Continuous process improvement.

Figure 1 shows the interrelationship of these elements. The 5ESS switch project has adopted specific strategies and approaches into a quality management system (QMS) for implementing these elements and achieving success through TQM.

Panel 1. Abbreviations and Acronyms

FDAF—feature definition assessment form
OFI—opportunity for improvement
PQMI—process quality management and improvement
QIP—quality improvement project
QMS—quality management system
TQM—total quality management

The Quality Management System

Historically, our management system was dominated by a project orientation. Project plans were developed to meet committed release schedules and then tracked and reported over many project milestones. This approach focused almost exclusively on managing the product.

We now recognize that the processes used to create products are as important as the products themselves. Documentation that describes processes used by project members in their daily work has existed, in one form or another, for many years. Unfortunately, because varying degrees of attention were paid to this "methodology" documentation, it often did not meet the day-to-day needs of the development community and was not uniformly applied. Process ownership and process documentation were not a priority of the organization. Process issues were seldom dealt with explicitly, and any ownership that did exist was incidental to product ownership.

Formulation of a process management function and the associated process ownership roles began in 1988 with the identification of process owners throughout the organization. The processes defined spanned the development phases of the project, from planning through hardware and software development, to system verification, first office application, and customer support. Using the process quality management and improvement (PQMI) guidelines[2] for direction and methodology, the owners met on a monthly basis to discuss roles and responsibilities.

Over the next three years, multilevel teams of both engineers and managers were formed in each of these process areas. These process management teams have shaped the process management structure that exists today. Later in this paper, we describe this structure in detail, along with the tools and techniques used for process management and some specific lessons learned as the structure evolved during the past three years.

The concept of process management has matured and gained acceptance in the organization. Two aspects of process management that have required focused effort are defining the interface between product and process owners and aligning process management with the needs of the project and the business.

The interface between process and product owners continues to evolve. Prior to the identification of process owners, the product owners controlled both the processes and their execution. Now our goal is to differentiate carefully between process and product, and to have clearly defined responsibilities for both process owner and product owner, as follows:

- Process owners define the process; product owners use or execute the process.
- Process owners focus on improving (making changes to) overall process capacity (cost, quality, timeliness); product owners focus on delivering the right product to the right customer at the right time.
- Process owners authorize experimental changes to the process; product owners conduct those experiments.

Quality assurance is necessary to assess whether the implementation conforms to the process definition. Rigorous quality assurance of the products in the 5ESS switch project has traditionally been exercised by the development organization. Multiple quality and productivity criteria (called Q-gates) were established for each phase of the development process that had to be satisfied before substantial work could begin on subsequent phases. In addition, a strong verification function tests products both in the laboratory and on site. However, expanding quality assurance to encompass process validation is a necessary and crucial step, especially where there are many process implementors. This

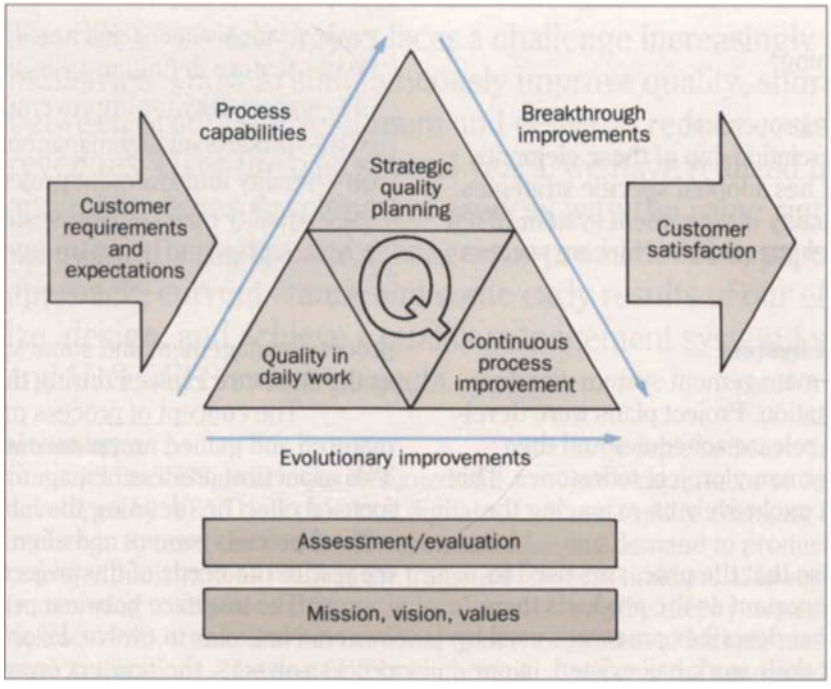

Figure 1. Key components and goals of TQM.

expansion of quality assurance is currently in progress.

Ensuring that process management is aligned with the needs of the project and the business is vital to its effectiveness. Without this mechanism, process owners may implement process "improvements" that are locally optimal, but have either no positive effect or perhaps a negative effect on the project as a whole. To maximize the results of process management, each process owner must understand the common goals of the organization and how their process goals relate to the whole. To accomplish this, the 5ESS switch project uses policy deployment (described in the next section).

Policy Deployment

Policy deployment, also known as *management by planning* or *Hoshin planning*,[3] is a process used throughout an organization to translate a vision or direction into coordinated action plans. In a quality management system, it aligns the various improvement activities in the organization. Our approach to policy deployment is based on the following steps:[4]

1. *Develop long-range vision and goals*—Based on long-term directions established by the AT&T Network Systems Group (NSG), the management of the 5ESS switch project develops a long-range vision for the organization and a set of long-range goals consistent with that vision. They base this multi-year outlook on customer need, market analysis, competitive position, and other factors.
2. *Develop a one-year plan*—As soon as management formulates long-range vision and goals, it proposes and plans intermediate goals achievable within a single year. In addition to long-range goals, the annual plan must account for current business needs and the results of the previous year's plan. Examples of one-year goals include improvement in key customer satisfaction metrics to enable the NSG to exceed customer expectations, improving quality by reducing product faults and development intervals, meeting specific revenue commitments to increase shareholder value, meeting employee educational goals to increase employee involvement, and many others.
3. *Deploy the plan throughout the organization*—When the annual plan is developed, the goals are deployed throughout the organization to the appropriate process management teams or line organizations, who together with project owners and coordinators develop action plans for their processes for the coming year. These action plans include not only how a process management team will meet its goals, but also

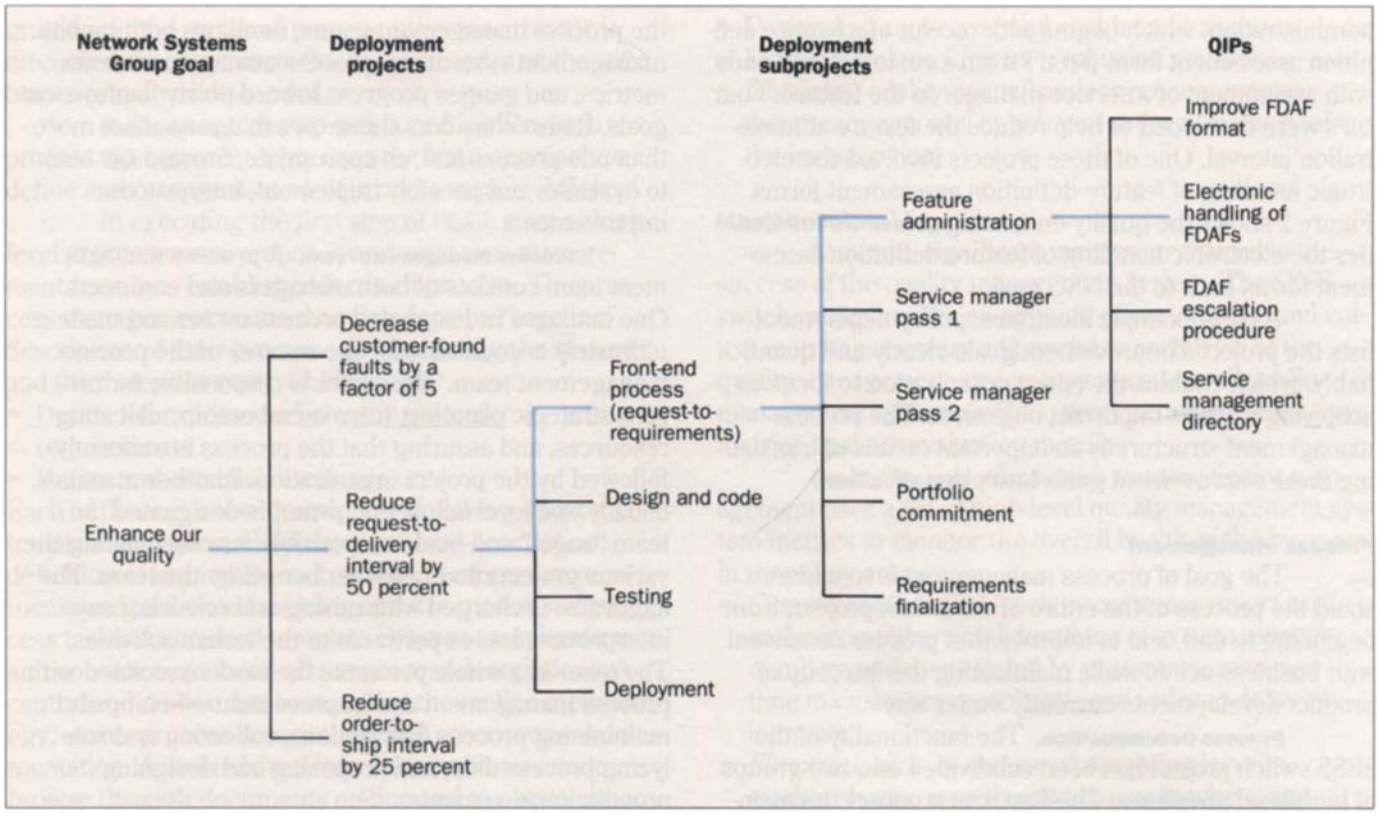

Figure 2. The quality-enhancing golden thread ties electronic handling of FDAFs back to each AT&T Network Systems Group goal. Each goal is clearly and quantifiably listed and divided into policy deployment projects and subprojects. The QIPs help to reduce the feature administration interval.

how other process management teams can or must support each goal. These plans, formulated as a series of strategic quality improvement projects (QIPs), are reviewed by process owners, senior management, and, where appropriate, one or more process management experts responsible for identifying inconsistencies among projects. These reviews ensure that process management team efforts are consistent and support the deployed goals.

4. *Execute the plan*—Projects are implemented over the course of the year, and data is gathered to determine if objectives are being met.
5. *Periodic review of results*—The status of all strategic projects is reviewed periodically by senior management to identify obstacles to progress and to focus on the process improvements themselves, rather than on the objectives.
6. *Annual review of results*—At the end of the year, a review is held to examine the results and how they were achieved. All projects are analyzed to improve the next annual plan.

Based on an NSG direction to improve quality, one goal of the 5ESS switch project in the United States is to reduce by 50 percent the interval between a customer's request for software features and their delivery. Each of four process management teams was initially assigned a goal to reduce subintervals in the front-end process, design and coding of software features, testing, and deployment. Process management experts who reviewed this assignment made slight adjustments to maintain consistency with plans to reduce development costs and delivered faults. Our senior managers reviewed the revised goals and formally assigned them to the process management teams. The process management team responsible for the front-end process divided its interval into five subintervals. One of these subintervals is feature

administration, which begins with receipt of a feature definition assessment form (FDAF) from a customer and ends with assignment of a service manager to the feature. Four QIPs were developed to help reduce the feature administration interval. One of these projects involved the electronic handling of feature definition assessment forms. Figure 2 shows the quality-enhancing *golden thread* that ties the electronic handling of feature definition assessment forms back to the NSG goal.

As this example illustrates, policy deployment lists the project's improvement goals clearly and quantifiably, which enables the entire organization to focus on achieving its most important objectives. The process management structure is an important means of translating these improvement goals into plans of action.

Process Management

The goal of process management is to understand the process of the entire 5ESS switch project, from beginning to end, and to improve that process consistent with business needs while maintaining the integrity of product developments currently under way.

Process Decomposition. The functionality of the 5ESS switch project has been subdivided into two groups of high-level processes. The first group covers the mainstream feature development life cycle. It includes the front-end process (feature definition and planning), software development, hardware development, office-dependent data development, end-to-end testing, first office application (cooperative testing and training on customer premises), and deployment and customer support. The other group of processes represents all the functions necessary to support the life-cycle processes. They comprise, among others, load integration (merging and compiling code), project planning and tracking, and control of the software development environment.

Structure. Because processes often cross organizational boundaries, the process management structure is similarly unconstrained by the organizational hierarchy. Currently, the process management structure consists of a quality council, process management teams, and QIP teams.

The Quality Council. The quality council contains the project's senior management, assisted by a dedicated technical support group. Its primary role is to set policy, direction, and goals for the process management teams. The council regularly reviews the progress of the process management teams, monitors both quality management system and process management team metrics, and gauges progress toward policy deployment goals. It also considers those QIPs that may affect more than one process and, as appropriate, forms a QIP team to evaluate, and possibly implement, interprocess improvements.

Process Management Team. A process management team consists of both managers and engineers. One manager is designated process owner and made ultimately accountable for the success of the process management team. The owner is responsible for process strategic planning, team membership, allocating resources, and assuring that the process is uniformly followed by the project organization. Another manager, usually one level below the owner, is designated the team "angel" and made responsible for coordinating the various projects and tasks performed by the team. The angel also is charged with raising and resolving any interprocess issues pertinent to the team's activities. The team as a whole performs the work associated with process management and improvement—writing and maintaining process descriptions, collecting and analyzing process data, and proposing and designing process improvements.

Policy deployment directives, root cause analysis of faults introduced during process execution, and internally generated suggestions for process improvements (called opportunities for improvement [OFIs]) are the primary sources of ideas for the process management teams to consider for QIP team investigation. Based on initial analysis, process management teams may decide to charter a QIP team to conduct a trial and possibly to implement a QIP as part of the standard process. The process management teams also collect and analyze metrics on their process performance, their contribution to overall policy deployment goals, and the QIP investigations and trials within their process.

After each product development cycle is completed, the process management team conducts a process postmortem. The postmortem presents the process quality data and sets directions and goals for future process quality improvement.

Quality Improvement Project Teams. QIP teams, which typically contain two to five members, are chartered to analyze and conduct QIP trials. If a trial proves that the QIP is cost-effective, the process improvement is inte-

grated into the standard process; otherwise the QIP is discarded. In either case, the QIP is closed, and the QIP team normally is disbanded.

Methodology. As we mentioned earlier, each process management team uses the PQMI approach to define and manage its area of process responsibility.

In executing the first step of PQMI, a set of high-level processes was proposed and a process management team was established for each process. The process management teams then developed a "baseline" description of their processes by executing the second and third steps of PQMI, which are to:

- Define the process and identify customer requirements
- Define and establish measures.

Each of these process descriptions follows a standard template, including a high-level process description, definition of key inputs and outputs, customer requirements and associated metrics, and descriptions of process tasks. A standard template ensures completeness and consistency among all the process descriptions. A centralized on-line database, called the on-line methodology, stores process descriptions and other process documentation. A menu-driven interface enables users to browse through documents on-line and to obtain either electronic or hard copies of any document.

During the next two steps of PQMI, which are to:

- Assess conformance to customer requirements
- Investigate the process to identify improvement opportunities

each process management team gathers and analyzes metrics data and uses this information, along with the process definition, to propose process improvements. In addition, the OFI mechanism readily allows any project member to identify a process problem or suggest a process enhancement. Process management team representatives automatically receive electronic copies of OFIs written for their processes, and OFI authors receive electronic notification of the disposition of their OFIs as soon as they are executed.

The next steps of PQMI, to:

- Rank improvement opportunities and set objectives
- Improve process quality

set the improvement process in motion using QIPs. A standard QIP process has been designed to assure that proposed process changes are investigated in a thorough, methodical fashion. In particular, the QIP process requires

- Performing root cause and cost benefit analyses
- Defining and tracking QIP evaluation metrics
- Obtaining quality council and/or process management team approval to proceed at specific stages of the investigation.

Measurements

Accurate, significant metrics are crucial to the success of the quality management system. The 5ESS switch project makes an ongoing effort to define and collect metrics necessary and useful to each level of the quality management system structure: overall quality management system metrics, process management team metrics, and QIP evaluation metrics.

Quality Management System Metrics. Senior management uses a set of high-level quality management system metrics to monitor the overall health of the business in three key areas:

- *Customer satisfaction*, such as customer report card analysis, numbers and durations of system outages, numbers of defects found by customers, response time to customer complaints, and order-to-delivery intervals;
- *Financial*, such as measured operating income, market shares, growth rates in new markets, and development cost and productivity;
- *Internal organizational health*, such as morale, adequacy of training, confidence in management, and communication.

A successful quality management system must obtain positive trends in each of these key areas. Some of the high-level metrics involved, however, take place over a period of a year or more and are influenced by many factors. Therefore, although the final success of the quality management system must be measured using these metrics, other more direct measures, such as the process management team metrics, are needed to gauge quality management system success in the shorter term.

Process Management Team Metrics. Each process management team identifies and tracks those metrics necessary to manage its particular process. Metrics are generally required in:

- *Quality management system metric components*—Each process management team has one or more metrics that are aggregated (not necessarily combined linearly) into the various quality management system metrics.

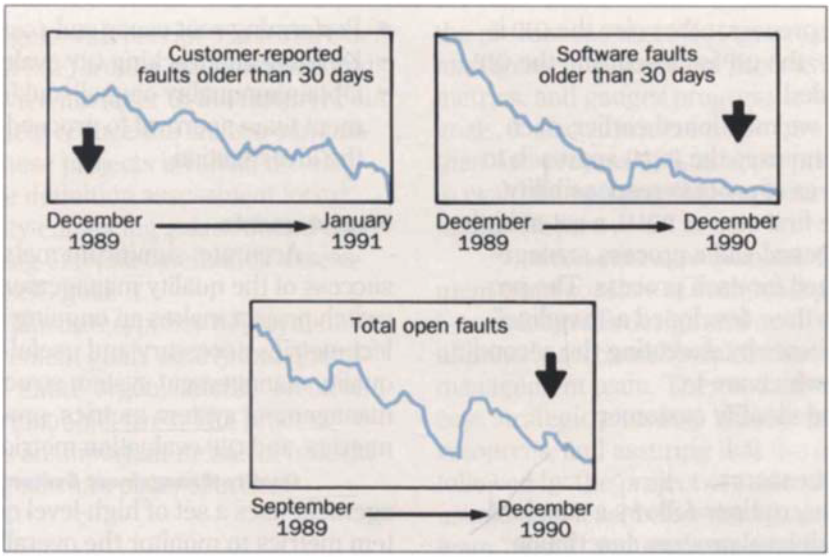

Figure 3. From September 1989 through January 1991, customer satisfaction visibly increased because of improvements in the process of handling customer complaints.

- *Customer satisfaction*—These are for both internal and external customers, and minimally include quality and timeliness metrics.
- *Process execution metrics*—Ongoing status indicators tracking key internal aspects of the process are used for day-to-day management.
- *Retrospective data*—Data items, typically computable only on a quarterly or annual basis, are used for long-range planning.

These process management team "key" metrics show whether the process is "healthy" and moving in the desired direction.

QIP Evaluation Metrics. Metrics are defined and implemented as part of every QIP evaluation plan. These metrics measure the expected success and benefits of the QIP. They may be existing or new, temporary or permanent, but they must always relate back to key process management team or quality management system metrics.

Results—Present, Past, and Future

Initially, the results of the project's quality and process management are measured by the framework in place. All identified processes have designated process owners and associated process management teams. Policy deployment goals have been defined and propagated throughout the process management structure. In the past eighteen months, process management has documented more than 2000 ideas for QIPs, and QIP teams have conducted trials on about one quarter of them. More than half of all 5ESS switch project members are part of a process management team or involved in a QIP trial.

Results can also be measured by the impact that several successfully completed QIPs have had on key quality management system and process management team metrics. For example,

- The initial modification request process management team in the 5ESS switch international project has improved customer satisfaction by improving the project's responsiveness to customer complaints (Figure 3).
- The process management team providing the test environment for the 5ESS switch project in the United States has reduced the cost of providing lab resources to the project while it has maintained its customer satisfaction rating (Figure 4).
- The software development process management team (U. S.) has reduced the average development interval in the database update and verification subsystem by over 30 percent.

Results can also be measured by the short time required for achieving registration under the International Standard Organization's standard for quality management systems—ISO 9001. To sell certain regulated products in the European economic community, suppliers, including those who sell telecommunications

terminal equipment, must comply with the appropriate ISO 9001 quality standard by 1993. Accordingly, the 5ESS switch international project quality system was assessed in October 1991. ISO 9001 registration was granted based on that assessment. The process of preparing for and receiving ISO 9001 registration, which usually takes an organization about three years, was completed in only 10 months.

Lessons Learned. While the total quality management effort for the 5ESS switch project is far from finished, we have learned that:

- Active support and participation from senior management is essential.
- A system-wide view of process is crucial to establish goals and directions that actually contribute to strategic business planning and satisfied external customers.
- Formal process ownership must reside at the level of management that can implement change. However, it is essential that all levels—from engineers up through senior management—exercise ownership for process improvement.
- Process work is a project—it must be planned, designed, implemented, and managed.
- Process work must have a dedicated staff, both within each process and in a centralized support and consulting organization.
- Communication with the entire development community is crucial to ensure commonality of goals and support of process change.

Future Challenges. As our process management infrastructure nears completion, our future challenges are to:

- Complete the infrastructure and move into the realm of continuous process improvement
- Show additional measurable results in quality management system and process management team metrics
- Strengthen the use of policy deployment as the mechanism to align our improvement efforts with business goals
- Define and achieve effective quality assurance in each process
- Continue to tailor our quality management system to meet the changing needs of our business environment.

Implementing total quality management for the 5ESS switch project has been and continues to be a challenging task. However, we have made substantial progress, and the potential for significant benefits in the future appears real. Given this, the motivation to continue to implement and tailor our quality management system remains strong as the 5ESS switch project moves into the future.

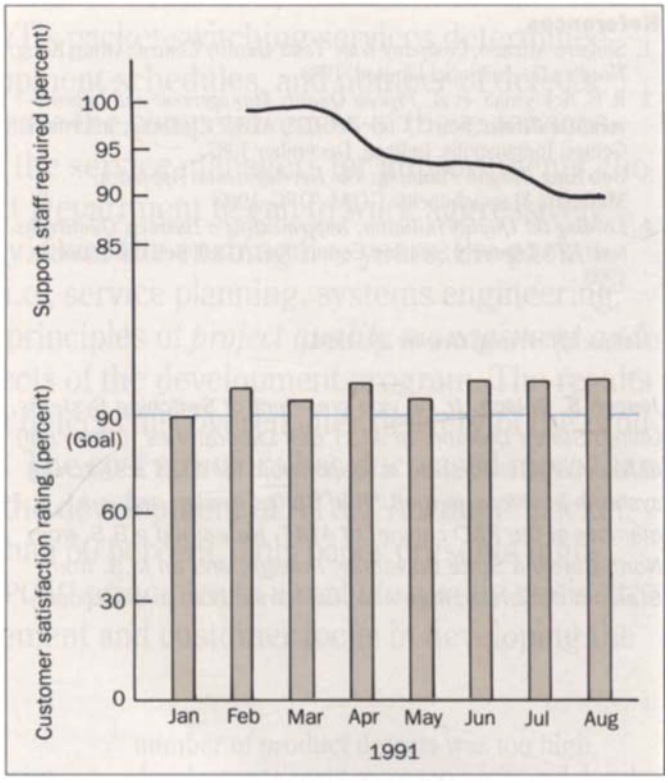

Figure 4. Implementing QIPs enabled the process management team that provided the test environment for the 5ESS switch project in the U. S. to reduce staff costs while maintaining the quality of service in system laboratories.

Acknowledgments

We thank the following people for their efforts: Ronald G. Basinger, Robert W. Bonvallet, Donald O. Carlson, David C. Carr, Harry Constantine, John P. Delatore, Michael J. DiMario, Donald H. Florin, Lynda M. Hakim, C. F. Hunnicutt, Susan M. Kania, Ronald Koestler, Thomas Pingel, John L. Reffett, Janis B. Sharpless, and Keith E. Wojnarowski.

References

1. Shigeru Mizuno, *Company-Wide Total Quality Control*, Hong Kong: Nordics International Limited, 1988.
2. R. B. Ackerman, et al., *Process Quality Management and Improvement Guidelines*, Select Code 500-028, AT&T Customer Information Center, Indianapolis, Indiana, December 1987.
3. Bob King, *Hoshin Planning: The Developmental Approach*, Methuen, Massachusetts: GOAL/QPC, 1989.
4. *Leading the Quality Initiative: Implementing a Business Quality System*, AT&T Quality Steering Committee, AT&T Bell Laboratories, 1990.

(Manuscript received October 29, 1991)

***Joseph S. Colson, Jr.**, is vice president of Switching Systems, United States Division, at AT&T Bell Laboratories (Indian Hill) in Naperville, Illinois. He is responsible for AT&T's switching systems business in the United States market and is a member of the R&D cabinet of AT&T. He earned a B.S. from North Carolina State University, Raleigh, and an M.S. from Stanford University, Palo Alto, California, both in electrical engineering. He joined AT&T in 1968.*

***Edward M. Prell** is vice president of Switching Systems, International Division, at AT&T Bell Laboratories (Indian Hill) in Naperville, Illinois. He is responsible for all aspects of AT&T's international switching business, including customer satisfaction; profit and loss responsibility; achieving financial objectives; strategies for introducing products on a global scale; and design, implementation, and service for local, toll, and gateway intelligent network and cellular applications. Mr. Prell received a B.S. in electrical engineering from the University of Kentucky, Lexington, an M.S. in electrical engineering from Columbia University, New York, New York, an M.S. in operations research from Stevens Institute of Technology, Hoboken, New Jersey, and attended Harvard's Advanced Management program. He joined AT&T in 1962.*