Competing in Large-Scale Software Development

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This paper provides an overview to the theme of this issue, the software-development process; i.e., the integration of practices, technology, and platforms into an environment for the development of software products. With a well-defined software-development process, an organization can optimize its development intervals, minimize costs, and maximize performance. In this paper, we describe the work going on in some AT&T business units to define and improve the process of software development and, thereby, shorten the time to market for products and improve product quality. In particular, we focus on two projects that provide mechanisms organizations can use to achieve and measure improvement in their software-development processes. These mechanisms emphasize the process and its components. By using these mechanisms, a software-development organization can choose the most appropriate practices, technology, and platforms to support its processes and measure the results of using these choices. Thus, the organization can quickly become process focused and reap the benefits of this approach to software development.

Introduction

An artisan creates a mosaic by arranging colored tiles to form a picture. When you stand close to the mosaic, you see the individual tiles, not the image. But as you move away, the edges of the tiles become less obvious and integration of the image takes place.

The software-development process is much like a mosaic. It is the integration of practices, technology, and platforms to form an environment for the development of software products. By itself, each practice, technology, and platform has value. But when practices, technology, and platforms are integrated, their value to the development community is multiplied several fold. (A *practice* is a recommended way of doing a task, while a *process* is the set of tasks to be done through practices. *Technology* is the method applied to achieve execution of a practice or a process, and may be an algorithm, tools, or methodologies. *Platforms* are the architectural framework within which we build products. A platform is usually instantiated by software systems and intersystem communications. Panel 1 defines acronyms and terms used in this paper.)

With a well-defined software-development process, an organization can begin to optimize software-development intervals, minimize costs, and maximize performance. Experience in AT&T with using a process approach to software development has demonstrated that substantial improvements in interval, costs, and product performance can be achieved. Through benchmark studies conducted in 1989 and 1990, several AT&T business units compared their speed in developing software against that of best-in-class companies.[1] These studies showed the business units where to focus attention to improve their software-development processes.

By applying a new process for introducing a new product,[2] AT&T's Operations Systems business unit focused the entire organization's effort on developing software more quickly and improving software quality. As a result, the average interval from identifi-

Panel 1. Abbreviations, Acronyms, and Terms

3DFS — a three-dimensional file system for managing software modules

ASCC — AT&T's Advanced Software Construction Center, located outside Raleigh, North Carolina

best current practice — a collection of AT&T work procedures and practices that are considered the most effective for performing a task or process

CASE — computer-aided software engineering

current engineering — the ability to maintain and enhance existing software

ISO — International Organization for Standardization, Geneva, Switzerland

ISO 9000 — an international standard that required suppliers to document their development processes and certify that they are following those processes

life cycle — the life of a product or service; starts with the initial concept for the product or service, and ends with its extension or replacement by a newer product or service

methodology — the processes, metrics, and documentation developed for a particular task or technique

`nmake` — a UNIX system tool for maintaining and updating multifile programs

NPI — new product introduction

platform — the architectural framework within which we build products; usually instantiated by software systems and intersystem communications

policy — the mandate that certain processes be used

practice — a recommended way to accomplish a task (also see *best current practice*)

process — the set of tasks to be accomplished through practices

SDE — software-development environment

SEI — Software Engineering Institute, a federally funded research center

STC — Software Technology Center; located at AT&T Bell Laboratories facilities in Columbus, Ohio, and in Middletown (Red Hill), Liberty Corner, and Murray Hill in New Jersey.

strategic directions — in the context of process design, the objectives (in terms of cost, performance, interval, and customers) for which the process is being optimized

time to market — interval from identification of a customer need to delivery of a product

quality gates — define specific entry and exit criteria for each phase of product development and a set of metrics to ensure that product quality is satisfactory

technology — the method applied to achieve execution of a practice or a process; may be an algorithm, tools, or methodologies

cation of a customer need to delivery of an Operations Systems product has been cut in half in less than two years. (We refer to such intervals as the *time to market.*)

Similarly, AT&T Business Communications Services has developed a fast-decision process[3] that expedites the execution of key decision points, so decisions and agreement can be reached quickly. This process-oriented methodology provides computer-supported quality tools and methods that help an organization select a course of action and generate the necessary project plans and schedules, proposals for new products or services, or requirements-design documents.

Also, AT&T's Switching business unit has developed a set of processes, called *quality gates*, that help it objectively manage and measure the quality of the output of each phase of the development process. Quality gates specify the entry and exit criteria for each phase of a product's development and define a set of metrics to ensure that the product's quality is satisfactory.

All these techniques—i.e., the new-product-introduction process, the fast-decision process, and quality gates—emphasize efficient and effective decision making.

In addition, the benchmarking studies have led some AT&T business units to reorganize their product development personnel into multifunctional, small teams.[4,5] Under this organizational structure, the key people with the requisite knowledge work together within, rather than across, organizational entities. As a result, the multifunctional, small-team structure allows decisions to be made more quickly and accurately than with conventional organizational structures.

Other studies were conducted to compare AT&T's product quality to that of best-in-class companies. These studies showed that our quality efforts were

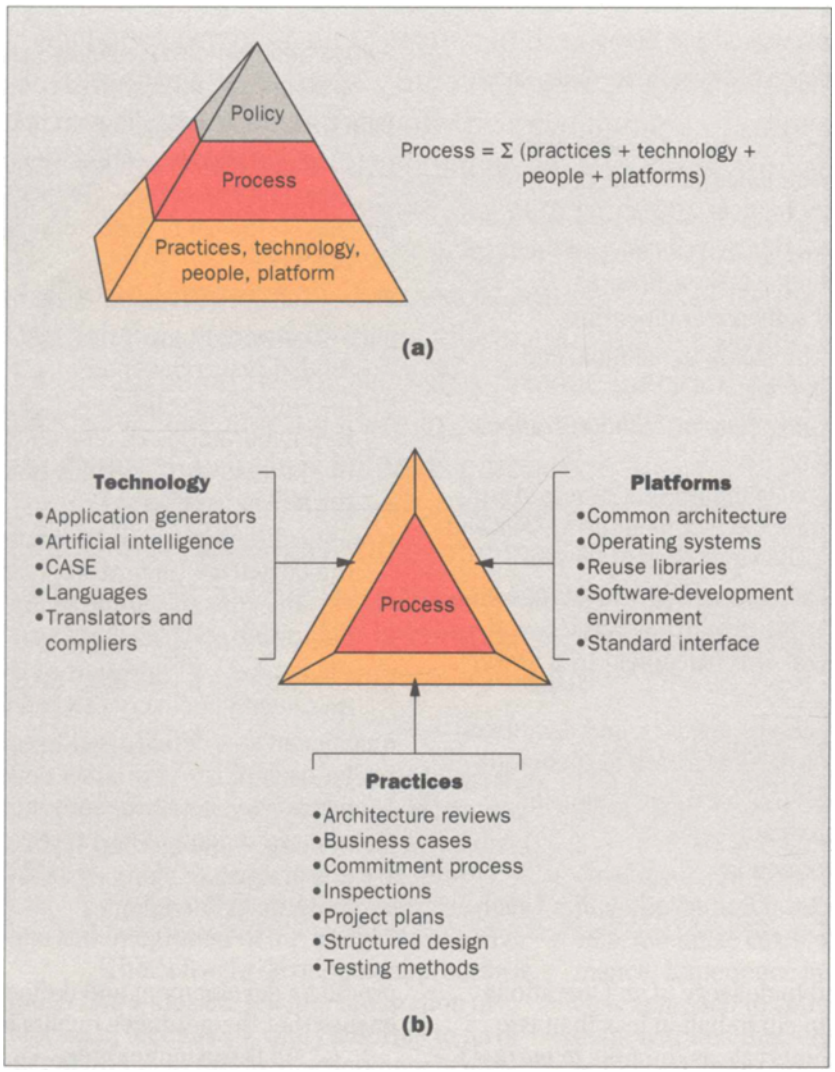

Figure 1. The challenge for AT&T's business units is to improve process capability within the context of an embedded base of people, practices, technology, and platform capabilities. (a) Here, process is defined within this context. (b) Relationship of these elements for next-generation software-development techniques. Listed are the areas of concentration for improving software productivity.

aimed at defect repair rather than defect prevention. From these observations, AT&T has developed the concept of *best current practices*. A best current practice is a collection of AT&T work procedures and practices that are considered the most effective for performing a task or process. Such practices have been judged by AT&T's expert practitioners in hardware and software development to have more quantifiable benefits than other methods. The best current practices have widespread applicability throughout AT&T.

This AT&T quality thrust has led to the development of such best current practices as software architecture validation, hardware inspections, code inspections, project-management audits, and the hardware-design checklist.

One challenge that product developers face in AT&T is to improve process capability within the context of an embedded base of people, practices, technology, and platform capabilities. Figure 1a defines *process* within this context.

As a first step to meet this challenge, Project MOSAIC in AT&T Bell Laboratories created a process-asset library that captures and integrates the knowledge about practices, platforms, and technology into an

overall software process.

In parallel with the effort to create a process-asset library about our current processes, AT&T is also working on a project, called "Silver Bullet," whose goal is to achieve radical improvements in product-development intervals. Project Silver Bullet involves the creation of a new organization that is specifically designed to execute highly advanced processes.

This paper will focus on the effect that a process approach has on software development and the major components (i.e., practices, technology, and platforms) of such processes. We will also discuss Project MOSAIC, which is aimed at deploying current best-in-class processes to all AT&T business units, and Project Silver Bullet, which is aimed at providing a next-generation environment for the development of Operations Systems products. Both projects have tried to capitalize on the benefits of the process approach by integrating the major components of processes. The other papers in this issue describe specific initiatives that are an outcome of this process focus.

Need for a Process-Engineering Discipline

As AT&T faces increasing competition in all markets and moves toward a stronger international presence, two facts have become clear. AT&T's processes and people are what will differentiate it in the marketplace, and the real competition lies in the effectiveness of these processes.

The leaders of AT&T's business units have set objectives that are focused on:

- Reducing product-development costs
- Increasing product quality
- Decreasing product time to market.

To achieve these objectives, AT&T has moved from being a technology-focused organization (where technology was used to drive practices and platforms) to becoming a process-focused organization (where the process is supported by practices, technology, and platforms).

Several process standards are also emerging in the industry, both domestically and internationally, and AT&T must conform to them if it expects to sell products and services that compete successfully in global markets. These standards, particularly the International Organization for Standardization's ISO 9000 standard[6] and the Software Engineering Institute's (SEI) process maturity levels,[7] require certification of both the effectiveness of a company's quality-management systems and the documented evidence that these systems are being executed. If AT&T is to use these standards, then highly efficient and measurable processes are not only necessary for compliance but, even more important, make good business sense.

How can AT&T's organizations achieve the necessary process-engineering focus? First, we should apply management-control techniques to all processes. Just as we manage our product development, we also need to manage our processes. We need to define, document, measure, and optimize these processes. We need to look for inefficient process steps and eliminate or reengineer them. We need to analyze the processes and look for areas of improvement to achieve higher levels of quality and further interval reduction.

Second, we should bring best-in-class practices to bear on optimizing the processes. We want to find the best-in-class practices within AT&T and from comparative studies outside the company. We need to apply those practices that are appropriate for particular projects or business units through the knowledge gained from our process analyses.

Third, we should insert technologies that help us execute and automate the practices. We want to choose the right tools for the job and integrate them into a development environment. We want to capture our repeatable work in platforms that maximize the reuse of components and the underlying software.

Finally, we should educate our people, so that they use the process approach effectively. They need to understand the new processes and the practices, technology, and platforms that support the processes. And, they need to understand the culture to get the real benefits these initiatives have to offer.

Components of the Process

Figure 1b shows the relationship among the practices, technology, and platforms.

The *practices* include AT&T best current practices, as well as other best-in-class practices for development. Best current practices cover the entire software-development life cycle, emphasizing not only product development but also interaction with and commitment to our customer. In this issue, one best current practice on analysis and design techniques is discussed in detail

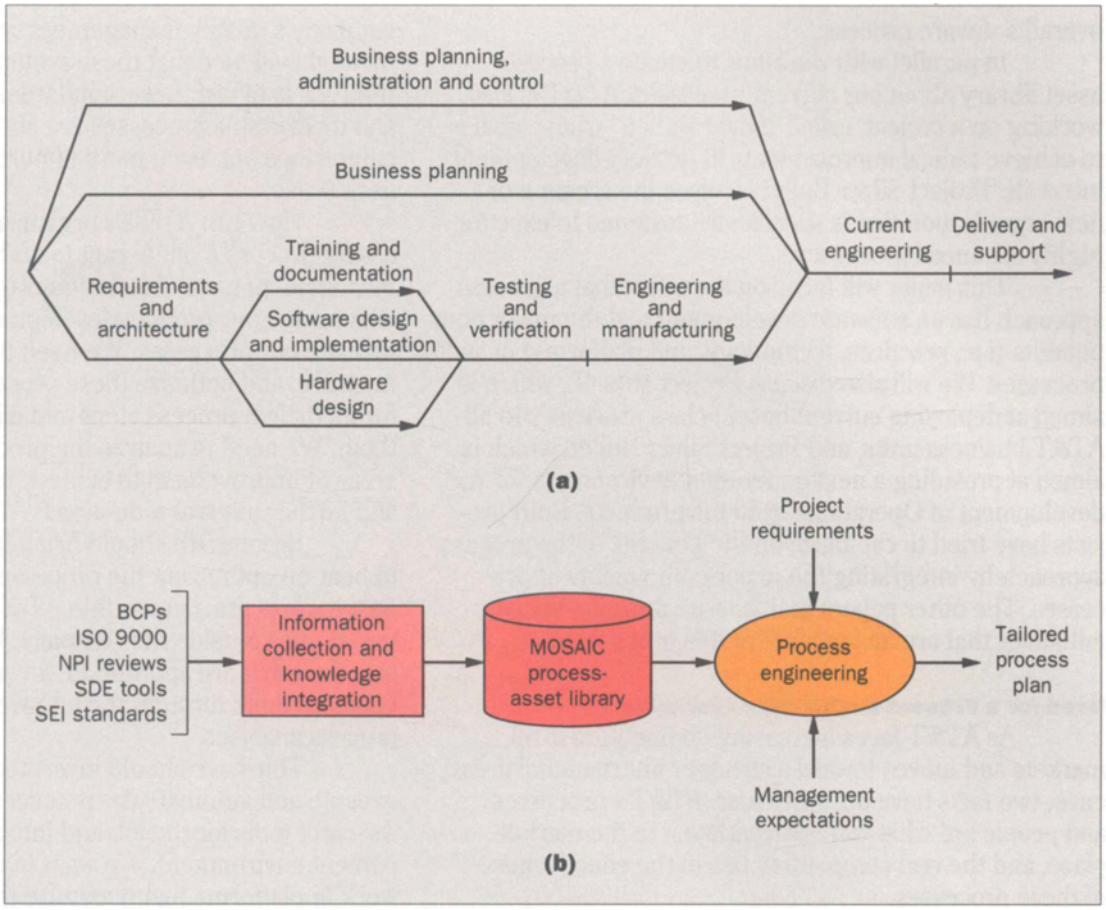

Figure 2. The Project MOSAIC process-asset library functionally covers the entire product-development life cycle. (a) The process model's overall structure illustrates the parallelism. To derive the functional areas, the Project MOSAIC team examined the key roles in development, independent of time and order. (b) A process-engineering support service helps projects use the process-asset library effectively. By using the library's accumulated knowledge and the results of process assessments, a project creates an action plan with specific, recommended practices, technology, and platforms.

in the paper by Kathleen Culver-Lozo and Vicki Glezman.[8] Business practices that are being followed in the new-product-introduction process are covered in the paper by George Arnold and Mark Floyd.[2]

Platforms are used to capture repeatable work and allow maximum reuse of both technology and products. A software-development platform is critical to help integrate AT&T's development tools within a seamless environment.

A product platform contains software that can be reused from one product to another. Because product platforms reduce the amount of new software that needs to be developed for an application, they also reduce testing cycles by providing field-tested software components. In this issue, the paper by Roger Beck et al. discusses[9] a platform geared toward transaction-based network management and operations-systems software.

Technology (or tools) supports the execution of the processes. Some of these technologies are or have been created through AT&T's research efforts. Examples of such tools are:

- C++, a language developed at AT&T Bell Laboratories for object-oriented programming.[10] (C++ is a descendant of the C programming language, which was also developed at AT&T Bell Laboratories.)
- `nmake` and 3DFS, UNIX® system tools for managing and controlling changes to software modules. (UNIX is a registered trademark of UNIX System Laboratories, Inc.)
- C5, a language for expert-system development.[11]

Other technologies are commercial tools, such as CASE (computer-aided software engineering) for collecting customer requirements.[8]

In this issue, the paper by Cecilia Castillo, Elizabeth Flanagan, and Nancy Wilkinson provides[12] more information about object-oriented techniques. The paper

by Glenn Fowler, Jim Humelsine, and Carl Olson discusses[13] the configuration-management subprocess and supporting technology, including `nmake` and 3DFS. The paper by Kathleen Culver-Lozo and Vicki Glezman describes[8] how the results of CASE studies are being used to improve processes.

Current research on software practices and technology is discussed in the paper by Dave Belanger, Eric Sumner, Jr., and Peter Weinberger in this issue.[14]

Project MOSAIC Process-Asset Library

To achieve repeatability in AT&T's processes, the Project MOSAIC process-asset library will be used to collect and integrate the best processes from the activities going on in the AT&T business units and in industry. This library will then be used to spread that knowledge to other projects through best current practices, technologies that enable process execution, handbooks, and training courses.

The library's contents are also a mechanism for:

- Accelerating the rollout of innovation through close cooperation with the AT&T Bell Laboratories research organizations
- Providing test beds of new technology
- Assessing the effect of new processes on product-development intervals and costs.

The Project MOSAIC process-asset library functionally covers the entire product-development life cycle, including business planning, documentation, and development. Figure 2a reflects the overall structure and demonstrates the parallelism that exists in product development. (For example, business planning runs concurrently with the software-development life cycle.) To derive the functional areas identified in the diagram, Project MOSAIC examined the key roles involved in software and hardware development, independent of time and order. For example, *delivery and support* would include the design transfer and manufacturing required for hardware, as well as customer delivery and support of both hardware and software.

An important objective of the library is to show how processes can be integrated and used in a consistent way throughout the life cycle. For example, the processes, practices, and tools used to collect customer requirements should be compatible with the testing and verification processes, so that testing would become a natural extension of customer requirements.

A second objective of the MOSAIC process-asset library is to maximize the commonality across projects. Thus, the company capitalizes on the lessons we are learning when all projects use the common processes, yet processes can still be customized for each project based on the needs of its customers.

The library describes the use of a software-development environment (SDE), which promotes repeatability by integrating both tools and practices. The software-development environment identifies when and what best current practices should be used, and implements them with the tools to support each phase of the life cycle. The research organization also plays an important role to bring new advances (i.e., innovation) in processes and technology to this environment.

AT&T has a long history of using audits and reviews as tools to improve development processes. We have evolved these methodologies, and standardized and customized the assessment instruments. Many projects routinely use project-management audits to improve their development planning and management. Many AT&T business units are participating in process assessments to evaluate their processes against industry and AT&T benchmarks to identify gaps. The assessment process provides comparative information on many aspects of the development process to help the business units assign improvement priorities.

While the business units work on initiatives to improve their development process and close the gaps in their assessed projects, the Project MOSAIC process-asset library is being used to consolidate the lessons learned for use across AT&T. Examples of initiatives that have been added to the library include:

- The quality-gates methodology from the Switching business unit
- Reusable assets and platforms from the Operations Systems business unit
- Robust testing[15] and the fast-decision process[3] from AT&T Business Communications Services
- Development test methods from AT&T Global Business Communications Systems.

Some of these initiatives (for example, development test methods) have become best current practices.

The contents of the Project MOSAIC process-asset library are shared with the business units through handbooks, best current practices, software-development-environment tools, and services to help projects use the

process effectively. As a result, users of the process-asset library in the AT&T business units can get a consistent set of practices and tools, together with training, to improve the repeatability and quality of their processes.

A new job function—process engineering—is part of this new approach to software development. A process engineer focuses on understanding available practices, platforms, and technology to develop an optimal software-development process. The optimization is based on a set of requirements, such as the interval, cost, and performance objectives.

Business units have begun to establish process groups to perform the new process-engineering tasks. These groups are using best current practices, platforms, and technology innovation to apply that knowledge to their projects. These groups can help transfer the process advances to line organizations.

A process-engineering service (Figure 2b) is available to help projects use the process-asset library effectively. With this service, a project can use the library's accumulated knowledge and the information obtained through process assessments to create an action plan with specific, recommended practices, technology, and platforms. Such a plan helps projects at their specific maturity level and life-cycle stage. The plan will measure the results of applying particular practices and technology against the project's business goals and evaluate the effectiveness of applying the recommended practices and technology.

Project Silver Bullet

Projects had shortened their development intervals through application of the Project MOSAIC process-asset library. However, the leadership of the Operations Systems business unit wanted even shorter intervals, levels well beyond the capability of even the best-in-class companies. Therefore, a new team, called *Project Silver Bullet*, had been formed in September 1990 to look for innovative ways to achieve an 80-percent reduction in AT&T's time-to-market cycles by 1995.

To achieve this goal and other, more immediate goals (i.e., a 44-percent interval reduction in 1992), the team chose a completely process-driven approach, coupled with a new organization designed to execute the Silver Bullet processes. The process approach enabled the Project Silver Bullet team to:

- Identify (and, if needed, design and develop) practices, technology, and platforms that were optimized for our specific domain (i.e., Operations Systems products and services) and objectives. (In addition to its time-to-market goals, the Silver Bullet team had cost and performance goals.)
- Apply a long-term, scientific approach to interval reduction. The team could baseline, measure, and improve the process. To baseline a development process, all aspects of it were identified including execution parameters, such as the time needed to execute the process. Thus, we could measure the development process and eliminate, automate, or replace aspects of it with more efficient approaches.
- Consider additional dimensions such as culture, staff, and training. New ways of developing software require new ways of doing business. Thus, existing organizations may need to change their traditional business methods.

With the goal levels of time to market in mind, the team chose an organizational revolution to support the process approach. Specifically, a process-engineering team was formed to design and measure the processes that Project Silver Bullet would use for software development. In addition, a new organization, the Advanced Software Construction Center (ASCC), was set up to apply these processes to Operations Systems products to achieve Project Silver Bullet's interval, cost, and performance objectives.

The process-engineering team and the Advanced Software Construction Center are organizationally and geographically separated. (See Figure 3.) The Advanced Software Construction Center, which opened in July 1991, is located outside Raleigh, North Carolina. The process-engineering function is part of an overall effort within the Software Technology Center (STC) to support Project Silver Bullet. The Software Technology Center is located at AT&T Bell Laboratories facilities in Columbus, Ohio; and in Middletown (Red Hill), Liberty Corner, and Murray Hill, New Jersey. Process engineering for Project Silver Bullet is at the Red Hill facility.

Figure 3 reflects the separation of process engineering from product development. The Software Technology Center provides platform, technology, and process capability to the Advanced Software Construction Center, which uses this capability to develop Operations Systems products to meet customer commitments.

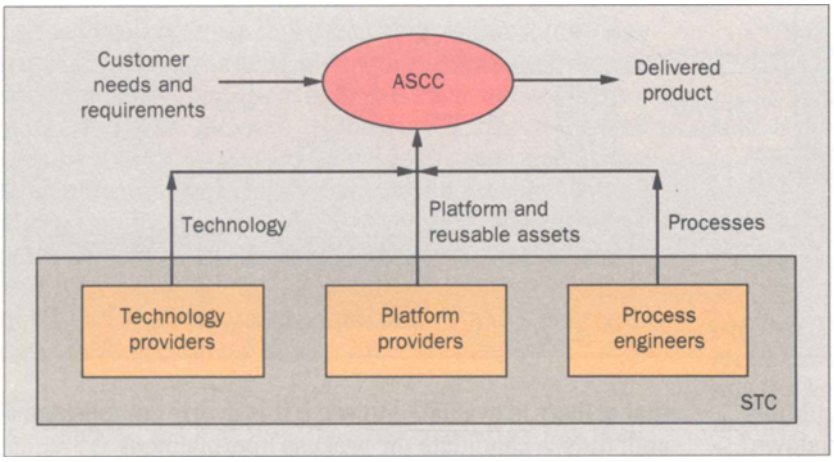

Figure 3. Structure of Project Silver Bullet. Process engineering and product development are separate. The Software Technology Center (STC) provides platform, technology, and process capability to the Advanced Software Construction Center (ASCC). The STC defines the process architecture and platforms to support process execution. The ASCC executes the processes and application and development environment platforms to develop Operations Systems products. It also gives the STC feedback about possible process improvements. Jointly, STC and ASCC teams collect and review the execution data.

The Software Technology Center is responsible for establishing the overall process architecture and the platforms to support execution of processes, and for exploiting process breakthroughs as they evolve. It delivers processes and the application and development environment platforms to the Advanced Software Construction Center. The Advanced Software Construction Center is responsible for executing the processes to develop Operations Systems products and for providing feedback on opportunities for process improvement. Jointly, the two teams collect and review the execution data.

The Advanced Software Construction Center opened its doors 10 months after the Silver Bullet team was formed. In those few months, processes to meet the 1992 interval objectives had been designed, a site for the center had been found, and staff to fit the processes had been recruited and hired. The process-engineering group focused, in turn, on process design, execution, and improvement. Before it could produce the complete set of information required to construct an appropriate process flow, the group needed to know who would be using the information. It also had to assess the individual needs of these consumers. Specifically, the analysis showed these consumers are:

- *Process engineers* who must define, track, and improve the processes
- *Managers* at the Advanced Software Construction Center who must manage projects (i.e., schedules), and hire and train staff
- The *staff* of the Advanced Software Construction Center who must use the processes
- *Providers* of tools, platforms, and practices to support the Silver Bullet processes.

Now that it had identified the consumers, the process-engineering group could address their information needs. It had to choose from among these needs the set of process information that would fully define the Advanced Software Construction Center's software-development process. For example, the center's managers need to know whom to hire (e.g., a staff member with a Bachelor of Science degree in computer science) and what training would be appropriate for that person (e.g., a unit-test course). The center's staff members need to understand what tasks they are responsible for, when to start a job, and how to know it is finished. The process engineers need to understand how much time currently is needed to complete each task in the time-to-market cycle before they can do anything to shorten the overall interval.

These "views" of the process were collected and the information used to optimize and improve the process. Training needs could be organized into a curriculum for all center personnel or for individual staff members. A development-environment platform (i.e., the integrated software-development environment) addressed technology or tool needs. The AT&T BaseWorX™ applications platform[9] supports the platform architecture of the Advanced Software Construction Center.

After the Advanced Software Construction Center opened in July 1991, the staff members went through four months of extensive training about processes, the BaseWorX application platform, and the software-

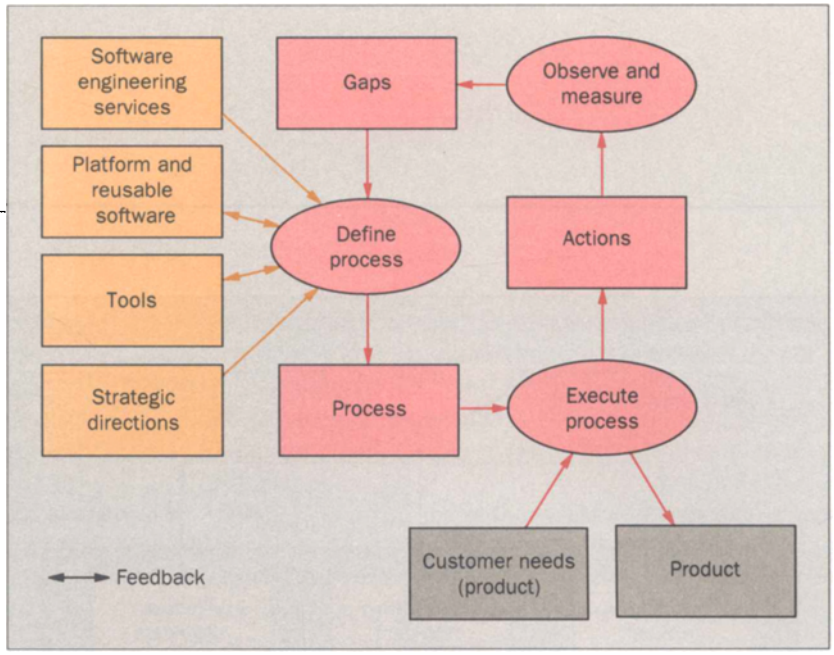

Figure 4. Process definition and improvement. The staff at the Advanced Software Construction Center partners with the process engineers to continuously improve the process. To define a process, they rely on engineering principles (e.g., stored knowledge and methods such as structured analysis), the tools and platforms captured in the Project MOSAIC process-asset library, and strategic directions (i.e., cost, interval and performance objectives). Feedback adds value to the asset library.

development environment—all part of the curriculum plan. Following the training phase came a "shakedown" phase during which the staff members executed aspects of the processes on a mock-up Operations Systems product. This process shakedown permitted the improvement mechanisms to be established and tested.

A key element of the process shakedown was the improvements that were identified and then incorporated into the processes and supporting platforms. The objectives of the process-improvement activity were to gain rigor and clarity in the processes, improve platform capabilities, and reduce intervals.

Figure 4 illustrates the process definition and improvement activities. The staff at the Advanced Software Construction Center partners with the process engineers to continuously improve the process. To facilitate communication between both groups, the processes have been put under configuration-management control, a strategy that has traditionally been applied to product development. Thus, all members of Project Silver Bullet participate in the identification of potential problems, and participate in their resolution as well.

When configuration management is applied to a process, attention focuses on the problems the staff members may encounter during project execution. Other data are also collected and analyzed to identify needed process-improvement activities. As projects are executed, daily time reports are collected from each person and then analyzed to see:

- How well the estimated staff hours matched the measured hours
- How much time is being expended on overhead (i.e., on tasks not associated with execution of the process that is being assessed) and on rework.

When an activity's measured hours exceed the estimate, that activity is evaluated to see if it is overly complicated and, thus, a candidate for process improvement.

To date, the Advanced Software Construction Center has applied the Silver Bullet processes to two products:

- An expert system. The center has met its first customer delivery of this product within the interval objectives.
- A billing system that is scheduled for delivery in early 1993, and is currently in the architecture phase of development. This project is meeting its individual task objectives.

As a result of the initial process shakedown and the execution of the processes for both products, more than 200 process improvements have been identified and implemented.

Project Silver Bullet is aptly named. Fred Brooks first used the term[16] to point out that no "silver bullet" (i.e., a single technology) can slay all "werewolves" within software development. Project Silver Bullet is consistent with that view. The breakthroughs will be achieved through integration of the practices, technology, and platforms; the application of process control; and continuous improvement through process engineering.

Conclusion

This paper has discussed the impact that processes have on software development and the shift from a technology focus to a process focus in some AT&T organizations.

The Project MOSAIC process-asset library has been used to capture best-in-class knowledge about software-development practices, platforms, and technology both within and outside AT&T. The library also provides mechanisms for deploying the knowledge.

Project Silver Bullet has built on this knowledge to design a next-generation environment for software development. A key element of this environment is the partnering of the process-engineering team and the staff members of the Advanced Software Construction Center to identify process improvements during the development of products. Some elements of the Silver Bullet processes have already been incorporated in the Project MOSAIC process-asset library. This gives other organizations the opportunity to gain the knowledge being captured in Project Silver Bullet.

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(Manuscript received July 17, 1992)

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