9-606-042
REV: MAY 3, 2006

FRANCESCA GINO
GARY PISANO

# Teradyne Corporation: The Jaguar Project

Jack O'Brien looked at the clock in his car; it was 7:38 a.m. and he knew he would need some luck to get to his 8:00 a.m. meeting at Teradyne's Harrison Avenue headquarters on time. Traffic on Boston's Central artery choked amidst the lingering construction from the interminable "Big Dig." O'Brien was looking forward to today's meeting with Teradyne senior executives to reflect on the lessons learned from the Jaguar project, which O'Brien had led for more than three years. The project had been one of the most important efforts in Teradyne's 45-year-history. It had set out to create an entirely new semiconductor test-system platform. The resulting Ultra Flex system, designed to be flexible enough to allow customers to test a full range of semiconductor devices, was critical to the success of Teradyne's new competitive strategy.

The Jaguar project had marked a culmination of sorts in Teradyne's eight-year effort to improve its product development process. The Jaguar team had used a number of project management practices, including intensive up-front project planning, formalized tools for tracking project progress, and a more structured development process. Most aspects of the Jaguar project went exceedingly well. All of the major hardware, for instance, had been developed in record time, and with minimal deviation from the plan. The product had met the vast majority of its target specifications. Yet, at the same time, software, a major component of the program, had run badly behind schedule and was still not completed. In addition, total development costs came in 35% higher than initially budgeted. While some members of the Jaguar team embraced the project management tools, others strongly resisted, or simply ignored them. O'Brien explained:

> We used these tools to force discipline in the development process. With the data and information provided by the new tools we were using, we were able to know whether a team was kidding itself or was having work done at the right pace. Of course, it takes more than just tools: You need the right leaders in the right positions, those leaders being empowered and those leaders accepting the responsibility and accountability for their piece of project.

But others were more skeptical. George Conner, architect of the Jaguar system, thought the tools could be distracting:

> Ninety-eight percent of the time in meetings was spent trying to figure out whether the tool reflected reality, rather than discussing what to do. With the scheduling tools, you have to specify the sequence and structure of tasks in advance. But this is an art. As the tools get more complicated, you spend more of your time dealing with the tools, rather than asking the right questions.

---

Post Doctoral Fellow Francesca Gino and Professor Gary Pisano prepared this case. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsement, sources of primary data, or illustrations of effective or ineffective management.

In keeping with Teradyne's deeply held belief in continuous improvement, O'Brien and the senior management would now begin a process of dissecting the history of the project and gleaning lessons learned. The outcome of the process would affect the way Teradyne executed development projects for years to come. As the traffic inched forward, O'Brien became impatient. He hated being late.

## Teradyne and the Semiconductor Tester Business

Teradyne was the world's largest supplier of equipment for testing semiconductors, with sales of $1.8 billion (in 2004) and over 6000 employees working worldwide (see **Exhibit 1** for Teradyne's financial statement). Founded in 1960 by Alex D'Arbeloff and Nick DeWolf, two classmates at Massachusetts Institute of Technology (MIT), Teradyne initially focused on making equipment to test transistors and other electronic components. Their business involved a new breed of "industrial grade" electronic test equipment, known for its reliability, test speed, and technical performance. Over the next 30 years, as both the complexity and production volumes of semiconductor increased exponentially, Teradyne continued to invest heavily in R&D to stay on the leading edge of test technology.

During this time Teradyne had also diversified into other related electronic test markets. In 2004, Teradyne had five major business units—Semiconductor Test, Assembly Test, Broadband Test, Connection Systems, and Diagnostic Solutions—which were organized by the products they developed and delivered. Semiconductor Test was the largest business unit in the corporation, accounting for 64% of total company revenues in 2004. The Semiconductor Test unit had major engineering operations located in Boston (Massachusetts), North Reading (Massachusetts), Minneapolis (Minnesota), Tualatin (Oregon), San Jose (California), and Agoura Hills (California). Boston, North Reading, and Agoura Hills also housed the company's manufacturing operations. The company's internal manufacturing focused on final assembly and test (subsystems and components were outsourced). In addition, the company had sales and smaller engineering organizations dispersed throughout its major global markets, including Japan, China, and Germany.

### *Semiconductor Test Technology*

Semiconductors spanned a broad range of device types, which fell into two categories: (1) memories, and (2) system on a chip (SOC). SOC included microprocessors (logic), analog processors, digital, mixed-signal processes (combining digital and analog circuits), specialized devices for graphics and sound, and customized integrated circuits. Each type of device performed a different job in an electronic system. Regardless of their purpose, semiconductors were highly precise devices that performed complex manipulations of electronic signals. The ability of a device to perform its function depended on its design, but also on its manufacturing. Even the most minor flaw in the production process (e.g., an errant piece of dust, or a tiny deviation in specification) could prevent a device from working properly. The job of a semiconductor tester was to determine whether or not a chip met its target specifications. To do this, the tester essentially interrogated the device electronically (sending it signals, and then measuring the response). This seemingly simple task was, in reality, one of the most challenging problems in the entire electronics industry. To work as specified, a semiconductor had to be able to perform a wide range of operations under many conditions in concert with other components of an electronic system. The semiconductor test system had to determine whether the chip was capable of performing these operations in isolation. Thus, the test system had to simulate the environments of the electronic systems in which the device might be used. As devices became ever more complex and precise, this challenge increased exponentially. Prices for Teradyne's systems could reach $3 million or more.

### *Semiconductor Tester Industry*

In 2004, Teradyne held around 35% of the world market for system on a chip (SOC) semiconductor testers. The other major market leaders in this industry were Agilent (with a 10% share), Advantest, and Credence. The market for semiconductor testers, like the semiconductor industry itself, was highly cyclical. Customers—manufacturers of semiconductors such as Intel, Texas Instruments, IBM, Hitachi, Samsung, and contract manufacturers like TSMC—generally placed their largest orders for semiconductor testing equipment when they were transitioning to a new generation of technology whose testing requirements could not be met with existing equipment. Given the historically rapid rate of technological innovation in semiconductors, this made it imperative for test equipment companies to invest heavily in R&D and to hit "market windows." Generally, customers preferred to stick with existing systems to leverage past experience, familiarity, and training. Thus, once a tester company "won an account," it was hard for another company to dislodge them unless their service or performance was exceptionally poor. In choosing among vendors, semiconductor vendors looked for technical performance and features: could the equipment test their device? They also focused heavily on test economics, which were largely driven by test speed. This latter requirement was particularly important given that testing was often a bottleneck in the total semiconductor production process, and that margins in many segments of the semiconductor business were relatively low. Reliability was also an increasingly important demand of customers because equipment downtime was extremely costly to a semiconductor manufacturer. The ability of a supplier to maintain equipment and provide rapid technical support was considered essential to competing in this market.

## Teradyne Culture

Teradyne retained the strong engineering culture that had been imprinted by its founders. Many of its senior managers were well-trained engineers. Status was driven by performance, especially, technical competence. Dress was casual. Office spaces were cubicles, even for the company's most senior executives. The culture encouraged individual initiative. New recruits were warned that no one would tell them what to do, but it was their responsibility to "dive in" and "ask the right questions." Long hours were the norm. In general, the company fared well in recruiting engineers from top schools like MIT and retaining this talent over several years. Most of the company's senior executives had spent the bulk of their careers with Teradyne.

A major milestone in the company's evolution occurred in the early 1990s when then CEO Alex D'Arbeloff decided to transform the way the company operated through the launch of a "total quality management" (TQM) program. At the time, D'Arbeloff was increasingly worried that despite its outstanding talent, Teradyne was at risk of losing its competitive edge because its products were often late to market and suffered quality and reliability problems. As he looked around, D'Arbeloff realized that many of the company's basic operating processes were not under control. Their performance had not been measured, and there was no systematic effort to improve those processes. To redress this deficiency, D'Arbeloff embraced TQM (total quality management), a set of principles, philosophies, and practices that emphasized the continuous scrutiny and improvement of an organization's processes. An intensive period of training in TQM principles and tools followed for all employees, starting with the senior executives. D'Arbeloff insisted that everyone, starting with himself, follow TQM methodologies, principles, and practices doing their work. D'Arbeloff expected his direct reports, for instance, to use such TQM tools such as seven-step problem-solving processes, root cause analysis, and fishbone diagrams in communicating and discussing management problems. By the mid-1990s, after five years of intensive effort, Teradyne had embedded TQM into most aspects of work at the company. And, most importantly, results in most aspects of the company's operations—such as manufacturing quality and customer service—improved dramatically.

## Product Development at Teradyne

When he initiated TQM, D'Arbeloff had hoped it would transform the engineering organization as well. Unfortunately, by 1996, it was clear that TQM was not taking hold in engineering, as projects continued to be late and over-budget, sometimes by a factor of two. The engineers resisted the structured approaches to problem-solving, and saw TQM as an encroachment on their freedom. In 1996, D'Arbeloff launched a separate initiative focused on product development. The initiative—dubbed "revolutionizing product development" (RPD)—was put under the leadership of Ed Rogas, a senior vice president and 25-year veteran of Teradyne. The company's senior engineering leadership from various divisions was assembled into an Engineering Process Improvement Team (EPIT). Rogas and the EPIT, which met monthly, were charged with developing and implementing a new approach to product development throughout Teradyne.

At the time, the company's problems fell into two categories. First, the engineering organizations throughout the company were badly overcommitted on projects (capacity utilization was estimated to be as high as 300%). To address this problem, the company implemented a more structured and rigorous project capacity planning process known as Aggregate Project Planning (APP). There were two guiding principles of the APP process: (1) Undertake only those projects that aligned with the broader strategy of the company; (2) do not over-commit; only start projects when adequate and appropriate resources are available. While a seemingly simple tool to use, the APP required a great deal of behavioral change and discipline.

The second problem at Teradyne related to the execution of individual projects. Projects were poorly planned. The goals and scope were often not clearly defined up front and, as a result, projects tended to expand as engineers and marketers thought of additional features. Milestones were not well defined, and were often missed. Project schedules were put together with little rigor. Because there was no systematic method for tracking project progress, it was hard for senior management to know when to intervene unless major problems appeared. Finally, because projects were handled by individual engineering functions and there was no one individual responsible for the entire project, there were significant delays and quality problems caused by failures of coordination and communication. To address this second problem, the company launched several improvement initiatives. One was the creation of a "phase-gate" model for development projects. (See **Exhibit 2** for details on Teradyne's phase-gate model; see **Exhibit 3** for the Project Execution Strategy Matrix[1] developed for the Jaguar project.) The purpose of the phase-gate model was to provide well-defined milestones and review points. The second initiative was the implementation of project management tools designed to help teams plan projects, manage schedules, and track progress against goals. (See **Exhibit 4** for a description of project management tools.) Finally, in keeping with Teradyne's philosophy of continuous improvement, a structured "after-action" review was recommended after the completion of all development projects. Such reviews would bring together project team members and selected senior managers to explore the lessons learned.

Because it was against Teradyne's culture to mandate the use of any specific tools, it was left up to individual divisions and managers to decide which recommendations to follow. Some divisions of the company quickly embraced the approach, while others seemed to resist or simply ignore them. The latter was often a source of tension at monthly EPIT meetings where engineering managers were expected to report on progress in their divisions. Even within divisions, progress was highly variable. Some project managers followed the phase-gate model, engaged in more detailed project planning,

[1] The project execution strategy matrix (PESM) served as a framework for creating common understanding and controlled, well-executed critical decisions. It was developed by identifying the six capabilities inherent in any product development project and the underlying principles, processes, and structures that influence those capabilities.

and conducted rigorous after-action reviews, while others did not. Rogas grew increasingly frustrated with what he saw as "passive aggressive" behavior. More troubling to Rogas was the lack of behavioral change. He lamented: "Some people were going through the motions of using the tools but weren't really changing their behaviors. They were still over-committing. They were still coming up with unrealistic schedules. They weren't being intellectually honest."

## A New Strategy and a New Structure

Historically, Teradyne and other test equipment suppliers designed completely different test systems for each type of semiconductor device (memory, digital/logic, analogy, mix-signal, etc.). The advantage of this approach was that it allowed the design of the tester to be optimized to the test requirements of the particular device. Teradyne aligned its organizational structure with each market, with different business units focused on different device market segments: memory (MTD), logic (VTD), mixed-signal (ICD), microcontrollers (ITD), and system on a chip (SOC).

By the mid-1990s, changes in the market began to erode the logic of this strategy. In particular, as semiconductor manufacturers diversified into a broader range of device types, they were increasingly asking for a tester platform that could test multiple types of devices. This trend accelerated in the late-1990s with the growth of contract semiconductor manufacturers, whose business model was to offer a wide range of device-testing services. For these customers, utilization rates of device-specific testers were simply too low to be economically feasible. While Teradyne had previously offered flexible testers in the low/medium performance end of the device test market, Teradyne did not have a platform with the performance necessary to address the entire market. As Joe Wrinn, vice president of Platform Engineering, explained: "By the late 1990s, it was clear that this strategy was not working. The platforms were getting more complicated and costly to develop. It was becoming increasingly infeasible to develop multiple platforms."

Several of Teradyne's competitors had started developing a single tester platform in the late-1990s. Mark Jagiela, head of marketing for semiconductor test systems, recalled:

> Teradyne had been serving the market well with a variety of optimized products tuned to the needs of various market segments. When we saw the opportunity to move to a more flexible, consolidated platform strategy, several competitors were already moving in that direction. Therefore, although we had the advantage of bringing newer technology to bear on the architecture, we were going to be later to market.

In 2001, Teradyne senior management made a pivotal strategic decision to embrace a flexible platform strategy. The company reorganized, abolishing the market-segment-focused platform engineering organizations and folding them in to a single platform engineering group. A critical project of this new group—code-named "Jaguar"—was initiated in 2001 and aimed to create a highly flexible tester platform that could be easily adapted to the needs of different device segments. It was expected to be a major part of the company's revenue for the next 10 years.

## The Jaguar Project

O'Brien, a 25-year veteran of Teradyne's engineering organization, was appointed project leader. Almost immediately, he was faced with a thorny issue. Before the reorganization, Teradyne's engineering organizations in Boston and Agoura Hills each had their own flexible tester projects underway. The decision to launch the Jaguar project meant merging the efforts of these two teams.

But both the east coast and west coast legacy teams had their preferred approaches, and tensions arose over whose approach would "win." As Joe Carbone, manager of Analog Instrumentation Porting, reflected: "The merging of the teams created some tensions. This was not a group that came together willingly, and there were some battles over technical approaches."

From the outset, it was recognized that the project had to execute flawlessly. As Mike Bradley, then president of the Semiconductor Test division, noted:

> It was a simple but monumental strategic choice. We had a strong installed base of customers committed to our existing platforms. Going to a single, leveraged platform meant disrupting this installed base. This was risky, to say the least. And it meant that timing was absolutely critical. If we had stuck with our existing architectures, we could have made the argument to customers that our new products would be worth waiting for. But once we committed to a leverage strategy and a new, single-platform architecture, we just couldn't make this case anymore. This meant we had to get the new tester to market in as fast a time frame as possible, or we would open up many of our customers to the competition.

It was decided that mid-2004 was a critical target date for beginning shipment of the tester. Given how much was riding on the success of the project, the division and the corporate senior leadership took an early and active interest in the project. One area of early focus was setting a clear scope for the project. Bradley explained:

> The most critical decisions in product sizing are not around what you do, but around what you don't do. In the past we tended to go "all in" on front-end sizing, and we defeatured the system later when we couldn't hit the schedule. On the Jaguar, we had to take the opposite approach to be sure we would hit the market window. This was an uncomfortable change, but one we had to make.

In practice, this meant spending more time than usual in the early stages of the development process (concept development and product planning). Bradley and other senior managers pressed O'Brien and his team to clearly identify customer requirements and to commit to key product specifications. In addition, the senior leadership also pushed the team to identify all the critical technical risks and the contingency plans for managing those risks. As part of Teradyne's development process, major funding commitments for a project would not be made until senior management signed-off on the Phase 2 gate. Passing this gate required detailed analyses and a clear articulation of the product requirements. On the Jaguar project, this initially caused some frustration, as the team was anxious to get moving on the detailed engineering. [George] Conner commented:

> We have a tendency to pile everything into Phase II because senior management expects a high level of certainty before committing to the program. We end up having to produce detailed plans, schedules, and specifications at that point, and this leaves less room for experimentation in Phase III. I might be the only one with this perspective, but I think Phase II should be limited to identifying risks and understanding whether you can solve them in Phase III.

In May 2002, the Jaguar team came back to senior management with a 75-page presentation detailing the proposed system architecture, design, and functional specifications for critical subsystems, target performance specifications, and the project execution plan. Satisfied that the project scope was clearly defined, focused, and aligned with the market, senior management formally signed off on the Phase 2 gate.

## *Project Team Structure*

The Jaguar project was organized into a set of project teams, each of which was focused on a particular subsystem or task. (See **Exhibit 5** for an organizational chart of the project.) The sheer size of the Jaguar required drawing engineering resources and talent from multiple sites including Boston, Agoura Hills, San Jose (CA), Minneapolis, and Portland. To ensure appropriate levels of integration across the different sites and subteams, a "core team" was formed from the leaders of each of the subsystem teams. The core team also included a program manager, Kevin Giebel, and was headed by Jack O'Brien. The core team met weekly by teleconference and monthly in person to discuss the progress made by each team, and to make critical technical and organizational decisions. Senior managers, including Mike Bradley, Mark Jagiela, and Ed Rogas, routinely checked in with the teams on their progress.

Core team members were mainly Teradyne's veterans. As O'Brien commented: "The project started with a mix of who we needed and who was available. As time went on, the organization was continuously upgraded as talent became available. The most notable upgrade in both talent and capacity came when Teradyne decided to exit the memory business, which made available several leaders as well as about 60 engineers." The engineering part of the core team all reported into O'Brien. People on the core team knew that they were accountable to him for results. Giebel, who had just started working for O'Brien at the start of the Jaguar project, noted: "Jack could be pretty intense in these meetings. If your part of the project was late, he wanted to know why, and you'd better have a good explanation. He was great at drilling down to root causes. But it could make some people uncomfortable. He didn't provide a lot of psychological safety.

Carbone, who had also worked closely with Jack for many years, noted: "I didn't find Jack stressful to work for at all. Of the managers at Teradyne, I find him the easiest to work for. He's dead honest. And he's a great strategic thinker." Even those who thought O'Brien could sometimes be harsh were impressed with O'Brien's ability to shepherd such a complex project through development under intense pressure. In the words of Peter Breger, Jaguar Hardware Engineering manager: "There was no one better in this organization to pull off a project like this than Jack."

## *Project Management Tools and Processes*

One of the critical elements of the Jaguar project execution strategy was the use of formalized project management tools, including:

- *Work breakdown structure*, a detailed description of all the tasks required to complete a project, and their relationship to one another.
- *3-point estimation*, a technique for estimating the minimum (best case), maximum (worst case), and expected times required to complete each task.
- *Critical path analysis*, which used the work breakdown structure and the 3-point estimates to identify "bottleneck" tasks in the development process (i.e., those tasks that determined the overall lead time of the project).
- *Earned value analysis*, a method for measuring project progress by comparing actual and expected resources (or time) expended.

O'Brien was a strong believer in the value of these tools, particularly for a complex project like Jaguar: "We used a mixture of tools, such as critical path analysis, work breakdown structures, 3-point estimation, earned value analysis, and a project scheduling program called Primavera. The mixture helped us see different things that were going on. One size doesn't fit all."

O'Brien was convinced that these methodologies would provide a robust means to communicate the project status to management, and to identify critical issues (such as potential delays) that required senior management's action or support. To facilitate the use of the tools on the project, a separate "program management" function was established as part of the core team. Giebel was appointed program manager. Reporting directly to O'Brien, Giebel owned responsibility for ensuring that the project management tools were used and that the relevant data on project progress, scheduling, and the critical path were analyzed and available to the team. As one team member described it, Giebel was also responsible for "keeping the team honest." Each subteam had its own program manager as well. These program managers were responsible for tracking progress and analyzing data for the tasks of their particular subteam. To ensure convergence of the schedules across all the subteams, data were entered into a Web-based master scheduling program called Primavera, which could incorporate approximately 15,000 separate tasks.

The use of the tools involved different challenges for the hardware and software parts of the project. Giebel explained:

> In hardware, the physical attributes of a part often determine the appropriate sequence and structure of tasks. For instance, you cannot test a part until you have designed and built it. In software, you don't have these physical constraints. You can generally do tasks in almost any order. This gives you a lot more flexibility (as you execute) to shuffle people around to different tasks, and to even change the order of the tasks.

The inter-temporal relationship between every task was specified in advance so the program could calculate the impact of delay in one task on the other task, as well as the overall schedule. Primavera was used to identify the critical path (CP) at every point in the project. Giebel explained:

> We met every single week to analyze the CP. Our meeting involved debate and discussions about the CP. First, it was laid out and then it was reviewed by the team members. Everyone was expected to know what was on their CP. And this was actually not easy at all, since we went 10 layers deep on the CP report. In this way, most areas of the project were kept visible. In the creation of the schedule we used 3-point estimates. This meant that for each task on the project, three scenarios were taken into account: the optimistic, the most likely, and the pessimistic. We ran the project against the "most likely" durations. Our committed ship date was June 30, 2004, but the schedule was driven to an earlier date (March 31, 2004). This date was used in the CP report and kept lots of tension in the early milestones.

## *Project Performance*

An important principle established by O'Brien and the core team was to keep the June 30 first-customer-ship date fixed, regardless of delays of individual tasks. O'Brien reflected: "Even when we were consistently late with respect to what we expected, we never changed the end-point. We wanted to keep some tension in the process." In practice, this meant that the team had to be flexible in responding to delays, particularly those on critical path items. At monthly core team meetings, decisions would be made to reallocate resources to those parts of the project that had encountered delays. Additional resources were also made available to the team by senior management. (See **Exhibit 6** for Jaguar staffing requirements.) As Breger commented, "The project was luxuriously staffed. . . . Senior management spared no expense to make sure that the project wouldn't be delayed."

One of the key areas of management attention was the development of the five application-specific integrated circuits (ASICs) that formed the core of the system. These ASICs were on the cutting edge in terms of complexity, sophistication, and cost. In past projects, problems with ASIC development had been a major source of time delays (often six months to one year). In particular, the discovery of design problems late in the process often resulted in "re-spins" of the entire chip. To reduce the potential for such delays, the ASICs team on Jaguar invested heavily in simulation and other testing methodologies early in the development cycle. Wrinn commented, "historically, in ASIC development, we would spend most of our resources on development and very few on test. On Jaguar we reversed the ratio." This approach paid off, as virtually all of the ASICs were completed on time and with no major design issues.

While the hardware subsystems were largely able to keep on track, software development emerged as a problem. (See **Exhibit 7** for a timeline of the development process for the Jaguar project.) The new platform would utilize a Windows NT-based operating system called IG-XL that had been developed at Teradyne's Boston site for use on the platform called FLEX. Because Boston's software group was busy developing extensions to the existing FLEX product line and fixing bugs, the development of the Jaguar software had to be staffed primarily from Agoura. Paul Roush, who headed up this effort, noted that this caused some problems right from the start:

> Most of the developers on Jaguar had never worked with IG-XL before. A few had limited familiarity with an older generation of IG-XL. The experts on the IG-XL platform were located in Boston and were focused on extending and fixing the FLEX code base. These experts had little time to spend on Jaguar development. At that time the company priority was on FLEX, with frequent statements to the effect that, "If FLEX doesn't succeed, there won't be any market for Jaguar." The Jaguar development team underestimated the extent of the learning curve on the new platform. Even with what were intended and believed to be conservative estimates, we were running late.

Various project metrics indicated a problem. For instance, for the first year of the program, software was running at approximately 50% earned value per month. If this were correct, this meant that software was completing only one-half of the tasks that they had originally planned. Kevin Giebel noted: "Software was in denial. They kept saying they would catch up." When asked why the core team management or senior management did not intervene, Giebel reflected, "One of the reasons was that the management team did not pay enough attention to the data because of its skepticism around the metric." Conner added, "The software's problem emerged gradually. We just didn't see it until very late, but we all knew it was screwed up."

The team's ability to adapt was severely tested in September of 2003, when Teradyne received word that one of the largest semiconductor companies in the world, named AlphaTech, a huge potential customer, was about to commit to a competitor's system. Senior management viewed this as a serious potential blow to the whole program. AlphaTech's size, and its stature in the marketplace, meant that its choice had a powerful influence on the rest of the industry. Bradley commented, "The idea of putting a new product or a strategic customer at risk was not an idea we were going to take lightly. Our development team had to, and did, get fully behind the effort to have the Jaguar ready on time for this important customer."

The challenge was that Teradyne did not expect to have a system ready for evaluation until June 2004, almost 10 months away. Meanwhile, the competitor's system was already completed and in AlphaTech's evaluation laboratories. Rogas, who had worked closely with AlphaTech for more than 20 years, commented:

> We had to convince AlphaTech that they should wait for us and to overcome their skepticism. They knew from past experience that when we set a date we generally didn't hit it. This time, the only chance we had was to hit the target exactly. We all called everyone we knew at AlphaTech—people we had worked with for years—and asked them to give us a chance.

AlphaTech decided to give Teradyne a chance to bid on the business, but they made it clear that they would have to have a system ready by March 30, 2004, and they would tolerate absolutely no slippage in the schedule. Teradyne committed to a detailed schedule, with monthly reviews with AlphaTech management leading up to the March 30 ship date. Teradyne would not be allowed to miss a single milestone. Furthermore, it now had to incorporate very specific functionality required by AlphaTech that was not part of the original development plan. Given what was at stake in the AlphaTech order, there was little option but to commit. The subteams most affected were those that had to incorporate the new functionality required by AlphaTech. Carbone recalled: "The AlphaTech shipment put huge pressure on the team that was responsible for the large power-supply instrument. They were forced to finish their piece in half the originally scheduled time. This had nothing to do with process. It was pure pride. The people there were working 80-hour weeks.

The impact of the AlphaTech order was profound. Everyone noted that having a "real customer" with a concrete deadline was a huge motivator, but the accelerated timetable disrupted the project. While the hardware subsystems all managed to hit their new milestones, the software fell further behind schedule. In January 2004, senior management committed 15 additional software engineers to the project to counter the problem. Roush, who headed the software team at that point, reflected on the intense pressure:

> Bringing forward the first customer shipment date required pushing features out the door before they were ready. We had concerns, and those were discussed, but the core team consensus was that it was better to accept some risk and aggressively pursue the AlphaTech business than to walk away. There was a lot of pressure to meet the deadline. We were not being intellectually honest about the magnitude of the risks and the lessons from IG-XL history on FLEX.

As the deadline closed in, the software team shifted its effort almost completely to fixing bugs and getting an acceptable, operational piece of software to AlphaTech. Carbone stated: "The software team was under enormous pressure, and it just kept getting worse as it was slipping. The stress levels were off the charts. There was a lot of burnout. The fact that they lost very few people along the way is a tribute to Paul [Roush's] leadership. That team was incredibly loyal to Paul.

Carbone, who had worked in both hardware and software development during his 27 years at Teradyne, reflected on the challenges facing the software team: "When you work with hardware there are fixed gates in the process; the first board, the artwork, etc. These are tangible, hard points in the process. If they are not done, you know it. You can't lie to yourself. With software, it's much squishier. You don't have these points." Conner thought the problems were much more endemic to the company: "At Teradyne, we have an intuitive feel for what the problems in hardware are. We don't have that feel in software."

On March 30, 2004, as promised, Teradyne shipped the first complete system to AlphaTech for evaluation. All of the hardware subsystems met their specifications. The software did not incorporate all of the features initially requested by AlphaTech, and it was laden with bugs, but it was functional. For the next six months, the software team focused solely on upgrading the software and fixing bugs for AlphaTech. Roush noted, "We basically stopped doing development at that point, and just worked on bugs." And Carbone recalled, "They had to shift to pure firefighting mode. Any sense of process went out the window. They were no longer doing development; they were just trying to fix bugs for AlphaTech. By the end, they were coding day-by-day and uploading the software to AlphaTech over the Web." In June 2004, additional software engineers were added to the project.

The intensive effort paid off. In September 2004, AlphaTech selected the Teradyne system. The victory, however, came with its cost. Much of the rest of the project—including development of features for other customers—was delayed. In addition, software, completely consumed with bug fixing, fell further behind schedule. Additional software engineers were once again added to the project. In July 2004, Carbone was appointed to lead the remaining software development. "The situation was a mess. The people were burnt out. We had to add 50 more developers. We just used brute force. It wasn't pretty. We're still digging out."

The software challenge on the Jaguar program turned out to be bigger than anticipated. In December 2004, the hardware components of the now-named "Ultra Flex 1" platform were largely completed on schedule, and two large customers agreed to purchase the now-named "Ultra Flex" system (see **Exhibit 8**). However, due to delays in getting the software online, the volume production ramp of the product was pushed out six months. Jagiela commented: "The early indications are that we have the right product for the market. Competitive benchmarks are turning in the Ultra Flex's favor and we have a series of follow-on additions to the platform scheduled in 2005 to keep the momentum going. Pushing the volume ramp out six months beyond plan was a tough call, but we needed to mature the software more before we launched into wide distribution."

## *Reflections on the Project*

At Teradyne, the output of a development project was judged by two criteria: first, did the project achieve its target objectives and, second, did it build new organizational capabilities for future projects? While most people felt satisfied with the first, there was some disagreement on the second issue, particularly as it pertained to project management tools and practices. Some managers felt that, by and large, the project management tools worked and contributed to the success of the project. Their concerns revolved around the implementation. Others were much less convinced of the value of the tools, and were concerned that they could actually be a distraction.

Giebel was a strong proponent of the continued use of project management tools and saw the problems largely in terms of improper use. Giebel commented, "Too often, team members didn't know 'how to get value from the tools they were using' and thought they 'could have figured out what was wrong without them.'" Giebel believed that with more experience, and perhaps some additional training, this problem would be rectified.

O'Brien was also a strong believer in the value of the project tools. He saw the tools as working but was critical of himself and other members of the organization for not always reacting to the data. He noted, "Our problem was not a lack of data; it was to have data staring at us, and us not responding." Carbone, also a believer in the value of the tools, concurred with O'Brien's point. In recalling the struggles of the software team, Carbone noted: "The tools allowed the software team to lie to themselves. They kept rejiggering the critical path, putting things in parallel, adding resources, etc., to make it fit. Some very strong people allowed themselves to be fooled by the data. Jack let the metrics lie to him. The software disaster was evident from the EV,[2] but we ignored it (see **Exhibit 9**)."

Simon Longson, head of the Engineering Interfaces subteam, who had been at Teradyne for about 13 years at the start of Jaguar, thought the tools would have worked better if they had not

[2] Earned Value tool (see **Exhibit 4**).

encountered strong resistance: He explained, "People resisted the tools because they force you to commit. People are afraid to commit in an uncertain world. It's embarrassing to be wrong." Rogas also thought the project management tools added value. He specifically cited their impact on the AlphaTech effort: "The tools provided visibility into the project that we never used to have. This allowed us to respond to AlphaTech and be confident that could hit all the milestones."

Others sounded a more cautionary note. They worried that increasing emphasis on project planning, tracking, metrics, and reporting could distract team members from real problems. Ben Brown, engineering manager who had been at Teradyne for 21 years at the start of the Jaguar project, explained:

> It was natural that over time some people became more concerned about the metric in itself and not about what a poor metric was telling them. Plus, anyone can make any metric look good. You have to be careful: the metric might become the goal, so people focus on managing the metric rather than the project. People fall into this trap not because they want to do the wrong thing but because they feel pressure to manage to the metric. People need tools but, more importantly, they need the attitude. I do not think more sophisticated tools are necessarily better. Tools make things better if people using them accept and understand what they are for and how they work.
>
> This was not always the case for the methodologies we implemented. Sometimes, the tool got in the way. Think of Primavera, for example. Primavera is an awkward tool. The interface is terrible. Many of the first-level engineering managers hated it. Primavera requires a very static work breakdown structure; once you enter it, it is very difficult to modify. The problem is that as you execute a project like this, you actually discover things you have to do differently. But, the schedule is produced and updated using the original work breakdown structure. So the reported scheduled becomes less meaningful over time. Some groups had a weekly struggle with Primavera. They worked it to get the schedule completion date to come out OK by constantly rearranging the critical path, but missed the fact that deliverables in general were slipping and work was not getting done at the planned rate. Earned Value is another good example of tools that don't always work well. There are things that do not show up in the EV tool. You know how many hours you worked, but you don't know how much is left. You can make progress on EV without making progress on the project.

Brown took a short pause and then confessed: "I wanted to constantly challenge my people to think about new ways to execute the project. I let my people use Microsoft Project, but then I'd have my secretary type their data into Primavera so we could report it that way." Breger was also skeptical. He worried that the tools were driving out of some of the positive behaviors that were critical to success:

> In the past, a site like Agoura Hills owned the whole system. Now, the development is spread out all over several locations. This gives you a very different feel. You don't get that sense of ownership that drives people to come in on weekends. For the first time in my 26-year career at Teradyne, I didn't feel responsible for the success of the entire project. I felt responsible for reporting data. This is what tools were good at: providing lots of data. People were focusing on tracking data, but they didn't always worry about whether they were tracking the right data.

He also worried that the tools were too easily seen as a substitute for hands-on management: "The tools tell you if you're late, but you shouldn't need a tool to tell you that. If you have to find out from the tool, it's already too late. Plus, the tools didn't help me manage the most important stuff—

the uncertain stuff. EV, for instance, works great if you know exactly what you need to do. But development is not like that. There's a lot of uncertainty."

Conner was also concerned with the possibility of information overload. He recounted his observations from core team meetings: "People were focusing on details so much that they could not see the entire picture. In general, the tools do not help you focus on what decisions to make, they only provide you data and details on the progress of tasks. And the amount of data they provide can be overwhelming. Give me a 40-page schedule, and I'm lost."

## Looking Forward

As he finally emerged from his car, O'Brien was thinking what still needed to be improved for future projects. His thoughts kept turning to the project management tools and how their use could be improved. He could not help wondering whether Wrinn's words were right: "With the best possible processes, but with incapable people, nothing happens. But the opposite is not true. With capable people and lousy processes, a lot can be done."

**Exhibit 1** Teradyne Financial Statements

Summary of Operating Results (in $ millions except income per common share)

| | 2004 | 2003 | 2002 | 2001 | 2000 | 1999 | 1998 | 1997 | 1996 | 1995 | 1994 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Net Sales | 1,791.9 | 1,352.9 | 1,222.2 | 1,440.6 | 3,043.9 | 1,790.9 | 1,489.2 | 1,266.3 | 1,171.6 | 1,191.0 | 777.7 | 633.1 |
| Income before Taxes | 188.0 | (186.2) | (561.0) | (326.2) | 739.6 | 273.8 | 145.9 | 193.3 | 139.7 | 249.9 | 114.0 | 57.3 |
| Net Income | 165.2 | (194.0) | (718.5) | (202.2) | 517.8 | 191.7 | 102.1 | 127.6 | 93.6 | 159.3 | 76.4 | 48.1 |

Net Revenue (in millions)

| | 2004 | 2003 | 2002 |
|---|---|---|---|
| Semiconductor Test Systems | $1,146.3 | 735.4 | 557.5 |
| Connection Systems | 381.7 | 357.2 | 397.0 |
| Assembly Test Systems | 155.2 | 151.6 | 170.8 |
| Other Test Systems | 108.7 | 108.7 | 96.9 |
| | $1,791.9 | 1,352.9 | 1,222.2 |

Source: Teradyne website, www.teradyne.com.

**Exhibit 2** Phase-gate Model

| | **Phase I:** **Concept Development** | **Phase II:** **Project and Product Planning** | **Phase III:** **Detailed Design and Development** | **Phase IV:** **Product Test, Verification and Validation** | **Phase V:** **Product Release and Ramp** |
|---|---|---|---|---|---|
| *Objective* | Define market opportunity, customer requirements, product feasibility | Refine product concept and create development plan | Develop product to the point of a functional unit | Verify product meets specifications and prepare for customer shipment | Release product and processes to routine production, sales, and support |
| *Deliverables* | Preliminary market assessment<br>Preliminary technical assessment<br>Preliminary financial assessment<br>Mid-term plan alignment<br>Preliminary Project Execution Strategy Matrix (PESM) | Detailed product specification & functional requirements<br>Development plan including PESM<br>Business plan<br>Risk assessments | Functional unit<br>Test/verification plan<br>Final design documentation<br>Preliminary documentation<br>Customer requirements, specifications, and cost gap analysis | FCS -ready product<br>Execute test plan<br>Defined problem reporting and corrective action mechanism<br>Final user documents<br>Final customer training course<br>Field support trained<br>Proof of manufacturability<br>Final sales & marketing materials<br>Production ramp plan | Execute ramp plan<br>Release documentation<br>Project assessment<br>Product to market alignment analysis<br>Key account management plan<br>Product road map updated<br>Upgrade/retrofit plan (if needed)<br>Ramp, sustaining, enhancement resource requirements |
| *Team* | 2–6 people<br>Design engineering, Marketing at minimum | Core team (4–10)<br>Cross-functional (Eng., Mktg., Mfg., Sales, Support)<br>Appoint project leader | Full development team<br>Cross-functional (Eng., Mktg., Mfg., Sales, Support) | Full development team<br>Cross-functional (Eng., Mktg., Mfg., Sales, Support) | Development team<br>Cross-functional (Eng., Mktg., Mfg., Sales, Support) |
| *Gate* | Review of phase deliverables | Review of phase deliverables<br>Executive committee review | Review of phase deliverables | Review of phase deliverables<br>Corrective action plans | Review of phase deliverables<br>Confirm volume ship capability<br>Resolve key open issues |
| *Outcome* | Funding and resources for Phase II | Funding to develop product<br>Team commits to develop product | Ready for first test of parts<br>Ready for system verification | Product ready to ship in volume<br>Approval for First Customer Shipment (FCS)<br>First customer trained and ready<br>Support in place | Product built in required volume<br>Agreement that project objectives met<br>All development resources freed |

Source: Company information.

**Exhibit 3** Project Execution Strategy Matrix (PESM)

| Project Dimension | Principles | Process | Structure |
|---|---|---|---|
| *Project Definition* | - Project will have significantly competing objectives in the areas of cost vs. schedule vs. common platform functionality. Project will be defined to optimize the "sweet spot" of these competing trade-offs.<br><br>- Breadth of marketplace coverage and mid-SOC marketplace optimization will be favored over optimization for the cost or performance ends of the SOC marketplace.<br><br>- Universal slot architecture will be the key enabler to deliver needed SOC marketplace flexibility.<br><br>- We will consider the requirements of the stand-alone memory market segment for future derivative products, but will not make any significant trade-offs against our key project objectives.<br><br>- Project team is responsible for insuring a complete line of SOC instrumentation within one year of FCS. | - Existing technology & building blocks will be leveraged as long as there is minimal compromise against the prioritized program objectives.<br><br>- Decisions will be driven by the quantified impact against the metrics of the prioritized program objectives.<br><br>- Hierarchical Prioritized Objectives—(Prioritized Objectives for Jaguar and for each sub-project) | - Core team is responsible for the project definition<br><br>- Full time architecture team led by George Conner. |
| *Project Governance and Staffing* | - Staffing is assumed to be full time and dedicated to the project.<br><br>- Core team is responsible for the success of the program. | - Hierarchical Core Team integration.<br><br>- APP is the principle staffing management tool. | - Heavyweight Team organized into key sub-project areas. Sub-project leaders organized into a Core Team led by Jack O'Brien. |
| *Structure of Project Tasks and Activities* | - The project will use a single, integrated product development process.<br><br>- Tasks will be only assigned to people actively on-board with the project. | - Process will align to the RPD framework and will be built upon the consensus best practices that exist in STD. | - Full-time program management team with a full time resource per subproject. |
| *Design, Prototype and Test* | - Simulation will be utilized wherever possible as the first prototyping step.<br><br>- Physical prototypes will be required for any technology that has not been reduced to practice within Teradyne. | - Summarized monthly as part of risk roll-up. | - Strategy for each area owned by sub-project leaders. |
| *Senior Management Review and Control* | - Senior management review will be a time driven vs event driven cadence.<br><br>- Program metric gap analysis will be the focus of senior management reviews. | - Senior management will review the program at a monthly sponsor review.<br><br>- Program dash board for metric rollup. | - Review between Jaguar Core Team and Mike Bradley and his staff. |
| *Real-Time Mid-Course Corrections* | - Project definition is considered locked at the completion of Phase 2 unless there is significant change in requirements, risk or the competitive landscape.<br><br>- Trade-offs will be formally tracked and summarized monthly. | - Quarterly update of competitive PLA's and market segment requirements.<br><br>- Monthly rollup of key metrics, risks & VIT's. | - Monthly Core Team Face to Face Reviews<br><br>- Regular integration meetings with STD Market Teams. |

Source: Company information.

**Exhibit 4** Project Management Tools

*Work Breakdown Structure*

Work Breakdown Structure (or WBS) breaks a project down into its individual tasks and identifies the relationships between them. WBS has two major goals. First, to ensure that the project has all the work needed to complete the project successfully. Second, to ensure that the project includes no unnecessary work. By defining the project in this way, the WBS enables the project manager to clearly describe the hierarchical nature of the work to be performed and establishes a foundation for other elements of the formal project plan including the project's resource plan, budget, organizational plan and master schedule. WBS is indeed developed before dependencies are identified and activity durations are estimated. WBS is often used to identify the tasks for the Critical Path Analysis.

*Critical Path*

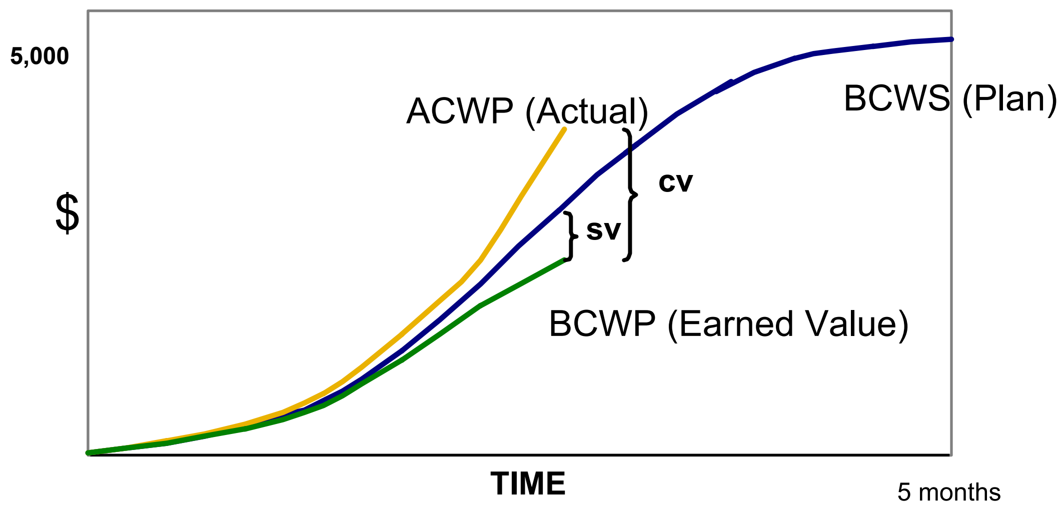
Critical Path Analysis (CPA) is a methodology to identify the set of "rating limiting" activities that determine the overall length of the project. CPA identifies those tasks that, if delayed, will cause the final completion date to slip. The main benefit of Critical Path Analysis is that it helps a company to identify the minimum length of time needed to complete a project. Where the company need to run an accelerated project, it helps it to identify which project steps it should accelerate to complete the project within the available time.

*3-point Estimation*

This is a technique to incorporate uncertainty into schedule estimates. For each task, a best case, worst case, and expected lead time are estimated. This technique can be used in conjunction with CPA to identify those activities in the project most likely to cause a time delay.

*Earned Value Analysis*

Earned value (EV) is a methodology for measuring a project's progress. EV compares the actual and planned amount of work completed (at various milestones) in terms of time or costs. An EV uses three metrics: 1) *Budgeted Cost of Work Scheduled (BCWS)*—planned cost of the total amount of work scheduled to be performed by the milestone date; 2) *Actual Cost of Work Performed (ACWP)*—cost incurred to complete work performed to date; 3) *Budgeted Cost of Work Performed (BCWP)*—the planned cost to complete the work that has been performed to date. By comparing differences in these three metrics, it is possible to identify two sources of variance: cost variance (cv) and schedule variance (sv).




The project is behind schedule if the schedule variance (sv)—computed as the difference between BCWP and BCWS—is a negative number. The project is over cost if the cost variance (cv)—computed as the difference between BCWP and ACWP—is a negative number.

Source: Prepared by casewriters from company information.

**Exhibit 5** Organizational Chart of the Project

Jack O'Brien: Project Leader

Kevin Giebel: Program Manager

Paul Roush: Software

George Conner: System Architecture

Joe Carbone: Analog Instrumentation Porting

Peter Breger: Core System

Simon Longson: DUT Interface

Ben Brown: Calibration & Accuracy, Digital Tempe ASIC, Ferrari ASIC

Ray Mirkhani: Mechanical

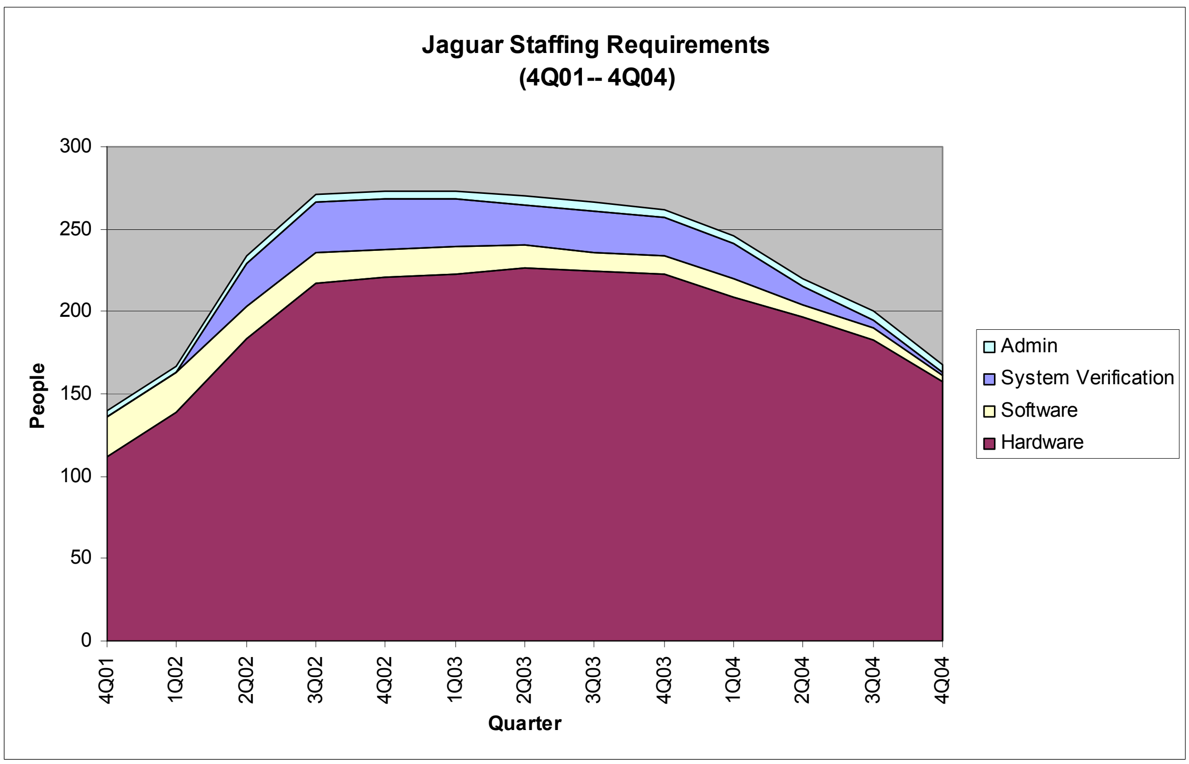
Tony George: Miata project (the new digital instrument that was part of Jaguar)

Brian Davie: Overall ASIC Functional Manager

Source: Prepared by casewriters from company information.

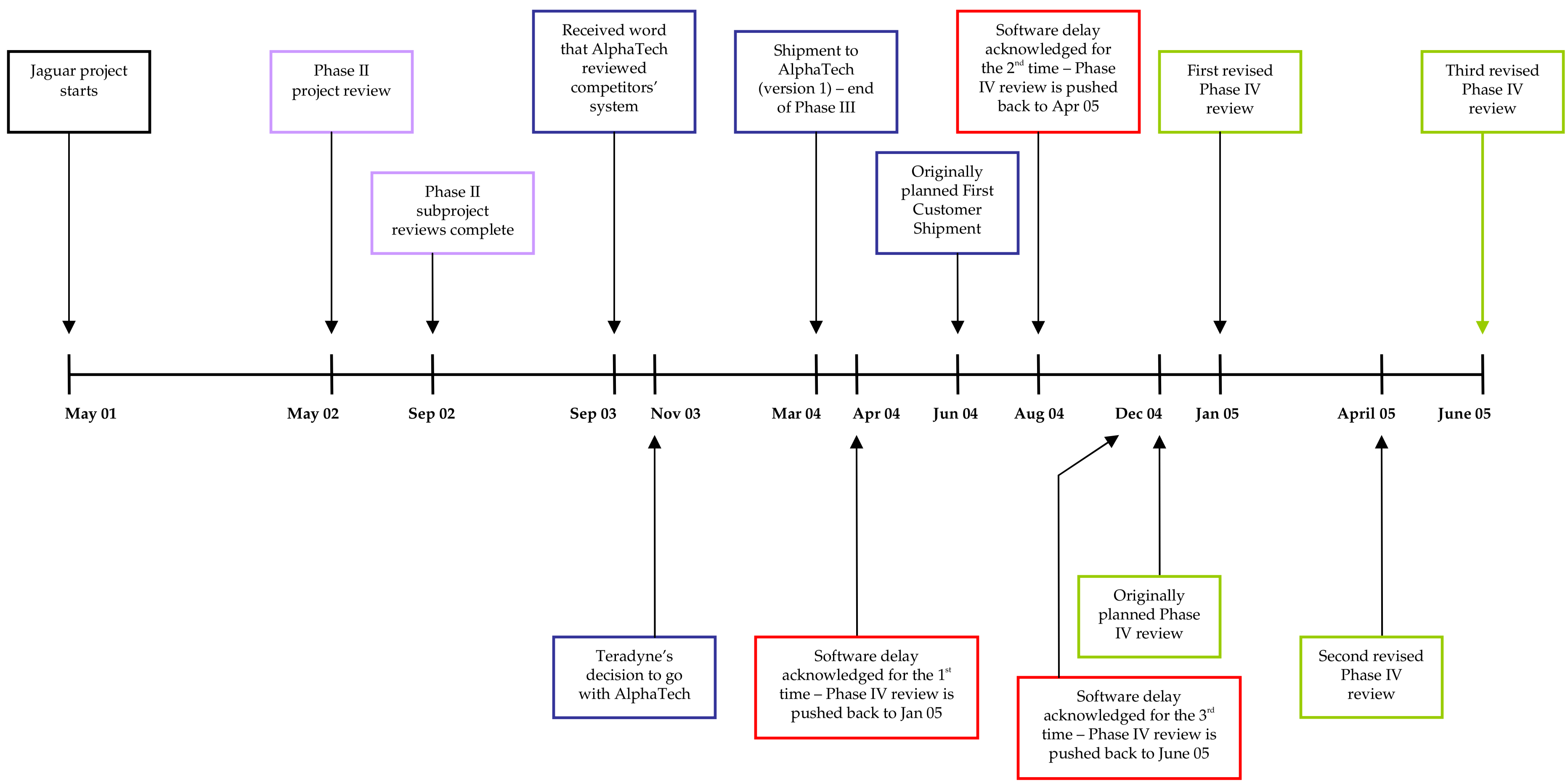
**Exhibit 6** Jaguar Staffing Requirements (Planned)

| | 4Q01 | 1Q02 | 2Q02 | 3Q02 | 4Q02 | 1Q03 | 2Q03 | 3Q03 | 4Q03 | 1Q04 | 2Q04 | 3Q04 | 4Q04 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hardware | 112 | 139 | 184 | 217 | 221 | 223 | 226 | 225 | 223 | 209 | 197 | 183 | 157 |
| Software | 24 | 24 | 19 | 19 | 17 | 16 | 14 | 11 | 11 | 11 | 7 | 7 | 4 |
| System Verification | 0 | 0 | 26 | 30 | 30 | 29 | 25 | 25 | 23 | 21 | 11 | 5 | 2 |
| Admin | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Total | 140 | 167 | 234 | 271 | 273 | 273 | 270 | 266 | 262 | 246 | 220 | 200 | 168 |



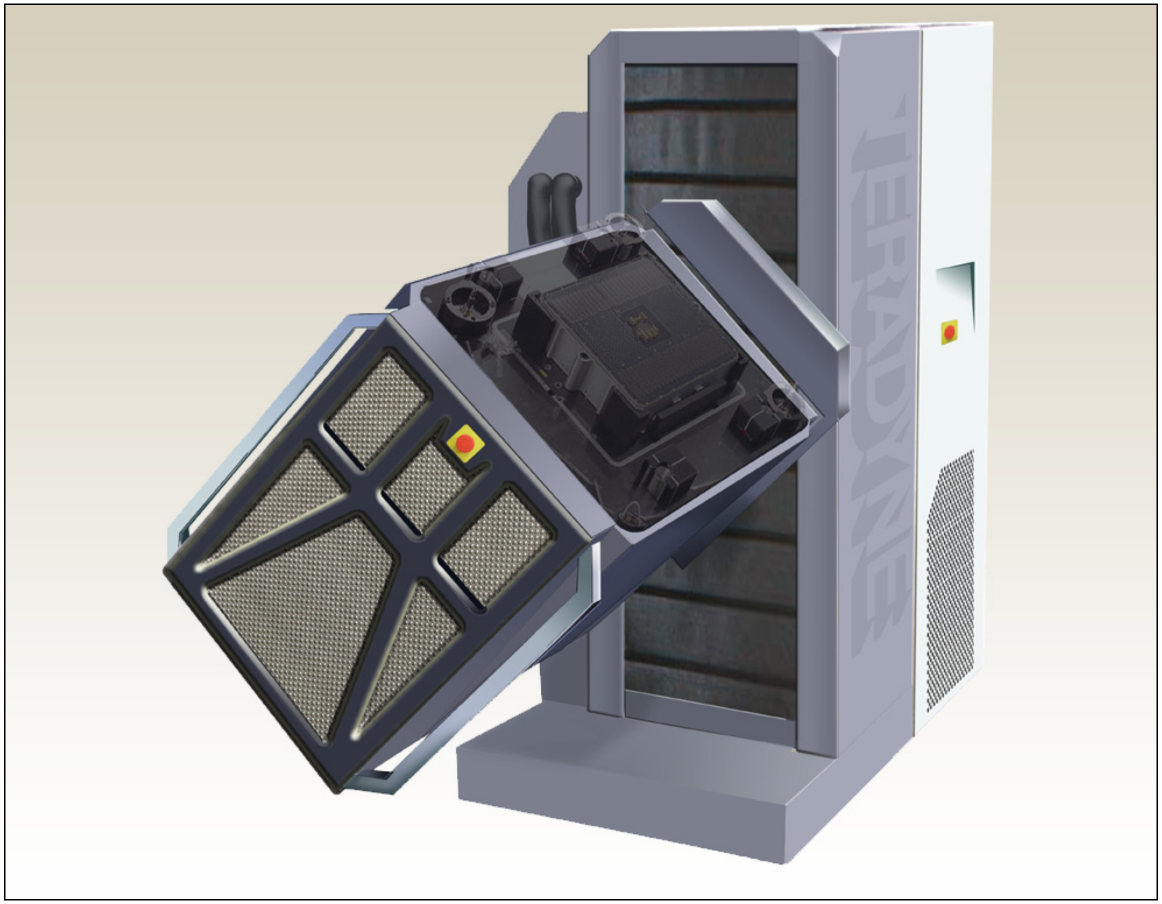

Source: Company information.

**Exhibit 7** Timeline of Main Phases of Development Process for the Jaguar Project



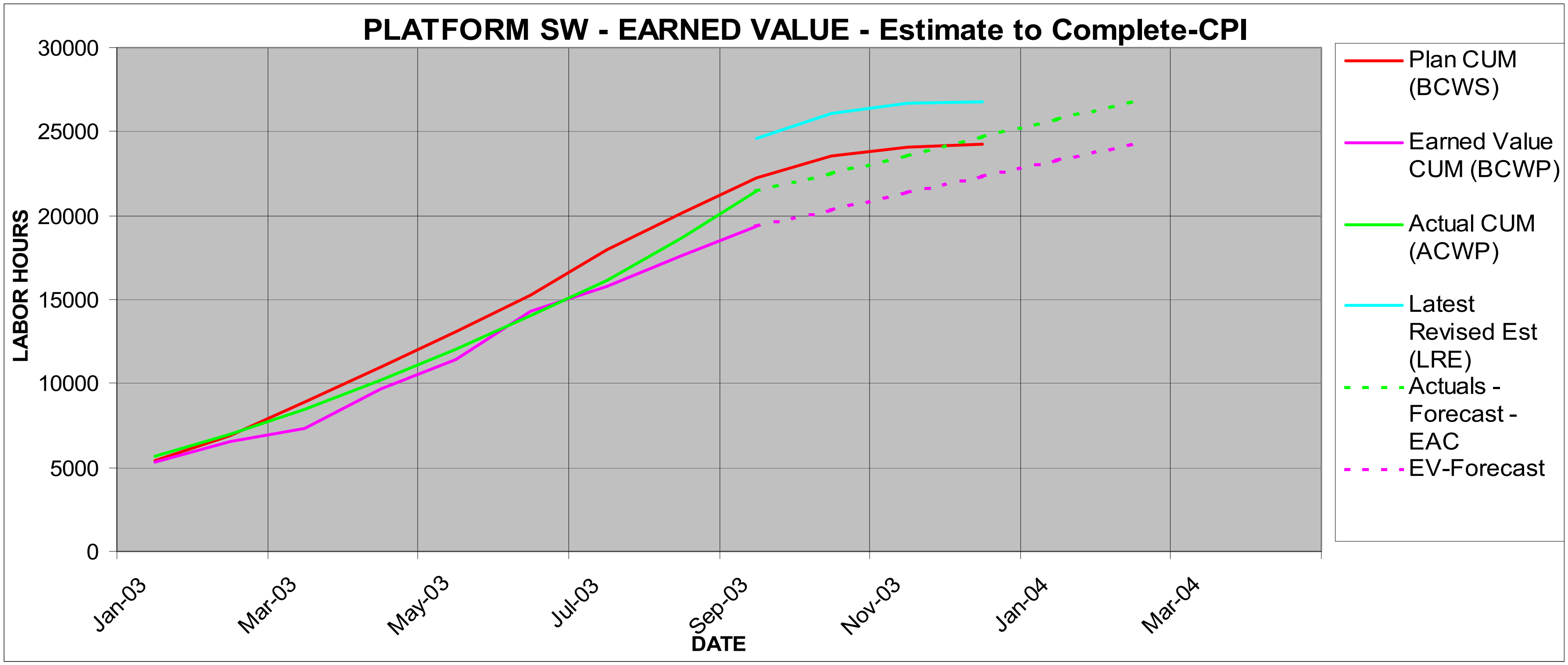

Source: Prepared by casewriters from company information.

**Exhibit 8** Ultra Flex Test




Source: Company information.

**Exhibit 9** Example of Data Provided by Earned Value Analysis




Source: Company information.