Patrice Dupass, GPS IIF Electrical Power Subsystem lead, holds a GPS receiver in front of a GPS IIF satellite at the Boeing satellite factory in El Segundo, Calif. At this location, 12 GPS satellites are being built on a pulse line. Next to the satellite are Cliff Davis (standing), integration lead, and Victor Visessonchok, test engineer.

PHOTO: BOB FERGUSON AND DANA REIMER/BOEING
GPS RECEIVER ILLUSTRATION: BRANDON LUONG/BOEING

They found the way

How the 'Never Lost' team helped Boeing's satellite team implement ideas from around the company—and meet the demanding production requirements of a GPS spacecraft contract

By Dave Garlick

The charge was to build 12 Global Positioning System (GPS) IIF satellites—incorporating the newest GPS technology and capability—for the U.S. Air Force. Build them on time and on budget; deliver all 12 spacecraft within a 36-month time frame and make sure each one works perfectly.

The hard part wasn't building the satellites. It was the number 12 that posed a challenge to Integrated Defense Systems' satellite division. "The going wisdom has been to build satellites in twos or threes like a craft shop, so we were forced to think way outside the box and not be afraid to try new things," said Dave Kadota, GPS manufacturing engineer and part of a 12-person team charged with figuring out the solution.

The GPS Assembly Integration and Test team met the challenge by asking a question: Why not apply to satellite manufacturing the process Boeing has used in building aircraft—the pulse line? After all, it's helped improve productivity in programs at both IDS and Commercial Airplanes. The team knew part of that solution would be to change an entire building culture. "It was a little like asking the people who hand-build Lamborghinis to start churning them out on an assembly line like Corvettes. That wasn't going to happen overnight," Kadota said. The team persisted and the idea was hashed out, researched and presented to GPS program director John Duddy who enthusiastically endorsed it.

"We—as well as the Air Force—were really excited about applying the pulse line to spacecraft," he said. Among the improvements it created: It cut the travel distance of a space vehicle in the factory by 2,000 feet (610 meters)." In the satellite building, that's a big deal because moving a precisely engineered satellite requires painstaking planning and flawless execution. A pulse-line configuration clears obstacles and makes much of the movement easier and safer. Creating a visual factory flow also provides a strong psychological boost to the team because they can see the final product as it moves, step by step, closer to the door.

In addition, the pulse line, which has been in operation since July, enables:

- A predictable workload and level production
- Reduction of work in progress, flow, touch time and defects
- Quicker responses to abnormalities
- Improved communications
- Optimization of resources.

In other words, by being willing to tap expertise from around Boeing, the GPS team made improvements that not only helped it meet a customer's high-volume need—but also boosted productivity. In fact, by the time the last of these satellites are built, the team anticipates an estimated 40 percent decrease in number of days needed to complete building the spacecraft, along with an estimated 30 percent drop in costs.

"The benefit of being part of a large diverse organization like Boeing," Kadota said, "is that there are so many ideas and resources across the board that can be shared. In our case, we borrowed and gave thanks to those who lent."

Over time, all Boeing's satellite production lines will adopt pulse line manufacturing, but the GPS program is considered optimal for introducing the process. "With 12 satellites on order, the GPS program is ideal for a manufacturing pulse line because similar satellites can easily adapt to a process that mirrors mass production," said Craig Cooning, vice president and general manager, Space & Intelligence Systems.

PULSE LINE, DEFINED

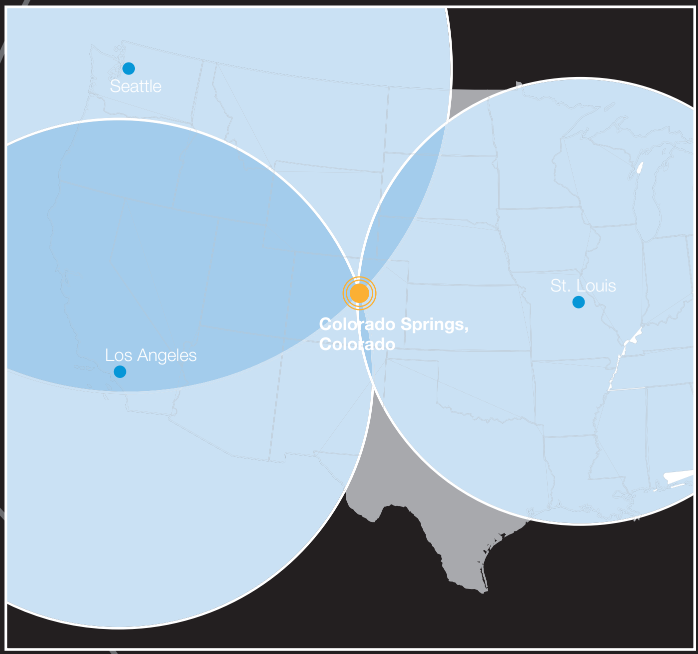
So, what exactly is a pulse line? A pulse line is really a modification of the traditional assembly line. But instead of the satellite actually moving down a conveyor belt, it is moved from one work area to the next in a steady rhythm, like a pulse.

The pulse line is far more efficient than the older style of satellite construction which was more like a craftperson's shop, which simply utilizes factory floor space as it becomes available. The pulse line divides the available space into work areas. The speed the satellite is moved, or "pulsed" from one work area to the next, depends on the work performed in one or two work areas critical to every satellite. Engineers know this work will take a certain amount of time, equipment and support, so the satellite only pulses forward when the work in that critical cell is done. This way, the satellite is "pulled" into the next work area instead of be-

(Continued on Page 15)

Finding yourself is quite simple

GPS might be seem complicated, but it's rooted in elementary trig principles



The GPS receiver is becoming another one of those gadgets we can't live without. The relatively small device has all but replaced the tried-and-true street map to help us get from point A to point B. But how does it do this? The concept behind GPS—made possible by the process of elimination and a little trigonometry—is powerful, but really very simple.

To understand GPS technology, you have to start with the concept of 2-D. Think of it as a flat plane that only has the dimensions of depth and width.

Imagine you are somewhere in the United States—lost. You ask a friendly fellow where you are. He says, "You are 1,066 miles (1,715 kilometers) from Seattle." That's a start, but not entirely useful. You could be anywhere on a circle around Seattle (except in the Pacific Ocean) that has a radius of 1,066 miles.

So you ask the same thing of the next person you see. She says, "You are 828 miles (1,333 km) from Los Angeles." That helps a little more, because now you can combine this information with the Seattle information and come up with two circles that intersect at two points (that's the trigonometry part). You know you are at one of those two points.

The next person you talk to says, "You are 772 miles (1,242 km) from St. Louis." Aha! Now you have enough information to eliminate one of the two earlier possibilities, because three circles can only intersect at one point. You now know you're in Colorado Springs, Colo. (See map above)

Now that there's no spot on any flat surface you can't find, let's add another dimension: height, or altitude. This same concept works in three-dimensional space—meaning that we're taking into account not only your location but also your elevation. This time, you are using spheres instead of circles, and GPS satellites instead of pen and paper.

A GPS receiver uses radio signals from the satellites orbiting above you to find your location on Earth. Think of the GPS satellite as the center of an imaginary sphere. You are at the other end of a radius line X number of miles away on the outside of that sphere. Your exact location will be where three or more spheres intersect. Here's how that works.

Let's say you're trying to find out where you are after a hike into the wilderness. You pull out your trusty GPS receiver and turn it on. The receiver calculates the distance between itself and at least three GPS satellites, based on the speed of light (186,000 miles per second or 300,000 kilimeters per second) and the distance the signal traveled (determined by the time it took the signal to arrive from the satellite). The receiver crunches all those numbers and finds that it is a certain number of miles away on the surface of an imaginary sphere around that satellite.

Now the receiver locates another satellite and does the same calculation. When two spheres intersect they form a circle, and the receiver knows it can only be located somewhere on that imaginary ring that forms where two spheres intersect.

By connecting with a third GPS satellite, the receiver can now narrow down its possible position to just two points, one in space and one on Earth. Indeed, the receiver thinks of Earth (including its atmosphere) as a fourth sphere, and since the trigonometry-savvy GPS device knows that four spheres can only intersect at one point, your position—and altitude—can now be determined.

It sounds simple. But don't forget that along with Earth rotating on its axis, the satellites are in constant motion in their orbits.

For the sake of accuracy, most GPS receivers generally try to find four or more satellites to improve accuracy and provide more precise altitude information. Commercial GPS signals are accurate enough for you to pinpoint your location within 3 meters, which is enough for most of us to find ourselves. The military can obtain much more accurate positioning.

—Dave Garlick

ing "pushed" forward by the next satellite coming up behind it.

Tracy O'Leary works in production control, which means she's responsible for getting the right parts to the right people working on the right spacecraft and at the right time. She said in her 25 years at the satellite factory, this is the first time all the pieces required for a pulse line have been put into place.

"We have been putting some Lean elements into practice on a smaller scale—for instance, keeping parts near the spacecraft so technicians wouldn't have to hunt for them. But everything really came together with GPS, and now we can take full advantage of that efficiency," she said.

The pulse line is organized like a surgical ward, to ensure all tools, supplies and equipment are available exactly where they're needed and when. "Surgeons—and satellite assemblers—don't want to run around fetching things," said Kadota. "We set up the line so that everything needed at a particular work area is right there within reach."

To ensure information flow, each cell has a scoreboard that shows who's working on the spacecraft, what work has been completed, what needs to be done, how long it will take and how things are going.

The decision about what information goes on the scoreboard is a collaborative effort. "What happens more often than not is that managers think they know what technicians need or like to see, but they don't always get it right," said Kadota. "We've tried to be mindful of what is important to the people on the floor."

The GPS team has until November 2011 to deliver all 12 satellites. If they are late, the expense could be substantial. "That's motivation!" said Larry Souverielle, deputy program manager for GPS IIF. "Everyone, from upper managers to floor technicians, is looking for ways to improve the build process."

Dave Kadota, a manufacturing engineer, helped find a way to build 12 GPS satellites on a pulse line and start a culture change along the way.
JOSEPH ORSILLO/BOEING

"The benefit of being part of a large diverse organization like Boeing is that there are so many ideas and resources across the board that can be shared. In our case, we borrowed and gave thanks to those who lent."

–Dave Kadota, GPS manufacturing engineer

According to Souverielle, by the time teammates get to the last satellite, they should be able to build it in about 247 days—much less than the 426 days if done conventionally. And the existing process has costs that are 30 percent higher than the new way. "I think we'll do better than the plan, which in itself is great progress," he said.

As exciting as all of this is, the GPS team realizes none of it is novel. Many of these ideas come from Lean processes implemented in manufacturing lines at Commercial Airplanes, as well as Integrated Defense Systems' C-17 airlifter.

NEVER LOST TEAM GETS IN GEAR

There's a 20-person Employee Involvement team in El Segundo, Calif., made up of production control experts, industrial and vehicle engineers, technicians and quality control people. They call themselves the GPS Never Lost EI team.

Their mission: Put together a world-class pulse line for Boeing's satellite factory in that city. That's exactly what they did—and in the process, they literally changed the future of satellite manufacturing at Boeing.

With an open mind and a willingness to learn and adapt, they set out on field trips to two Boeing locations that have successfully implemented a pulse line: Long Beach, Calif., where the C-17 is manufactured; and Renton, Wash., home of the 737 production line.

"We had never built satellites on a pulse line, so we were open to learn from teammates across Boeing who've been through the process," said Rebecca Taylor, the team's facilitator. "And the cooperation we got was phenomenal. Just an incredible willingness to share success stories."

First stop: Long Beach, where the C-17 aircraft has been assembled using a pulse line system and deriving significant benefits from Lean improvements since 1998. While there are definite differences between building a gargantuan airlifter and building an SUV-sized GPS satellite, the team saw where it could borrow

(Continued on Page 16)

ideas and best practices.

"It really slows things down if people working the floor have to leave their work area to search for a part, resolve an issue or get support," Taylor said. "So, the C-17 factory's work-cell structure and the surgical ward approach were things we knew we'd use."

Alan Worrell, a Lean manufacturing manager at C-17, said EI teams from across Boeing come to C-17 to see Lean principles in action. He and his group always impress on them that team integration is the key.

"Everything begins with the EI team. Every step has to start and be deployed through the employees. Their interest, their activity and their involvement is at the heart of Lean, and none of this works without it," he said.

Two Boeing technicians study the second of 12 GPS IIF satellites. Soon, these 12 spacecraft will be part of the 32-satellite GPS constellation.

BOB FERGUSON AND DANA REIMER/BOEING

Next stop for the Never Lost team: the 737 production line in Renton. The 737 line is used as a model—to Lean practitioners across Boeing and other companies—of how manufacturing should be done. There, they met Renee Leach, 737 industrial engineering and Lean manager. She and her group are charged with showing Boeing teams as well as outsiders how the ultra-Lean 737 factory has reinvented itself.

Leach stressed to the satellite EI team how critical it is for them, once they learn Lean principles, to take that knowledge and figure out how to make it work in specific applications. Accordingly, the team snatched up, among other things, the factory's scoreboard idea—that is, showing on an actual scoreboard all the vital information technicians need to know about the platform they're assembling.

"We saw right away that we could emulate their scoreboard," said Phil Kozel, manufacturing engineer and Never Lost team member. "There are some similarities between building satellites and building a plane, for instance, both require a lot of processes happening all at once. Seeing how the other organizations work made me appreciate how much transferrable knowledge there is at Boeing."

The EI team returned to El Segundo, armed with these and other Lean concepts and ideas. They shared what they learned with teammates, and today, in the satellite factory, GPS satellites are beginning to be assembled on a pulse line similar to what's been integrated so successfully in other parts of Boeing.

How do the C-17 and 737 teams feel about sharing what's worked for them? "We're one company. It's important to share our successes," said Leach. "We've enjoyed a measure of success here in Renton, but we also know the journey's long and we're not at the end. We love to share, and at the same time, we're continually learning." ■

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The biggest GPS story you never heard

In 2007, a Boeing team supported the Air Force in a successful upgrade of a computer system. No one noticed the transition—and that's a good thing.

To most people, Sept. 14, 2007, was just another workday. But had things gone awry for a Boeing team supporting the GPS system, it could have been Black Friday all over again.

On that day, a Boeing team in conjunction with the U.S. Air Force transitioned the on-orbit GPS system from one legacy ground control computer system to an upgraded system. And they did it live.

But the day came and went without notice. And that was good.

About 40 people on the GPS transition support team fanned out across the world to places like Hawaii, the Kwajalein Atoll in the Pacific Ocean; Diego Garcia in the Indian Ocean; Ascension Island in the Atlantic Ocean; Cape Canaveral, Fla.; and Colorado Springs, Colo.

Then, in phases over the course of that evening and the next day, the team began to move command and control from the mainframe-style computer system that had been running GPS since the 1980s, onto a new and upgraded Unix–based system and a Windows-based system.

If the team wasn't successful in this task, there would have been numerous problems, since GPS is so deeply entrenched in our lives. It's the foundation for how we do our banking and make our purchases. It's used by soldiers on the ground every day. It's attached to ground vehicles, helicopters, fighters, aerial tankers, bombers and ships. It has become routine on commercial airliners, cruise ships and cars. It even monitors the earth's fault lines.

But on that day, the system worked as usual—thanks to the Boeing/Air Force team responsible for the successful transition.

Despite the smooth transition, those who were part of the operation will tell you that the task was anything but easy: "It was like changing the engines on two truckloads of dynamite going down the road at 80 miles per hour," said Leland Horn, GPS sustainment manager.

However, Horn said he wasn't surprised things went well. "We had a sound plan, five years of planning and preparation, numerous tests and dry-runs to be sure it would work," he said.

—Dave Garlick

In this 2007 image, U.S. Air Force Tech. Sgt. Dana Ammend, a space systems operator with the 19th Space Operations Squadron at Schriever Air Force Base, Colo., uploads navigation and timing data to GPS satellites using the Architecture Evolution Plan system.

STAFF SGT. DON BRANUM/U.S. AIR FORCE

GPS may get boost from Iridium

While the GPS system itself continues to be upgraded, Boeing is also working on developing potential enhancements by pairing GPS with the Iridium low Earth orbit communications satellite constellation.

Under a $153 million contract the U.S. Navy awarded this summer, Boeing will work to demonstrate technologies of the system known as High Integrity GPS. The Iridium satellite system is currently operated by Boeing Service Company, a fully-owned subsidiary of Integrated Defense Systems.

"Our research concluded that significant low-cost improvements to GPS can be achieved by using existing signal platforms and systems such as the Iridium constellation," said Dave Whelan, IDS Advanced Systems chief scientist.

The system also is believed to have the potential of increasing access to location signals in areas where GPS signals may be weak or unavailable. Work on the contract is expected to run through 2010.

The system and technology originally was created and developed within Boeing Phantom Works and transitioned to IDS Advanced Systems at the end of 2007. "This is a great example of a team working across Boeing to potentially bring new, important capabilities to our customer," Whelan said.

—Marc Sklar