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The Weakest Link

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The Weakest Link

A product's vulnerabilities can point the way to lucrative new business opportunities.

by Nicholas G. Carr

When you think of modern aircraft, you think of big things: massive turbine engines, great expanses of sheet metal, elaborate electronic and hydraulic systems. Yet it was a very small thing — a two-cent piece of rubber — that played a crucial role in determining the shape and speed of today's planes. And the story of that piece of rubber reveals an important lesson about the path of technological advances and the focus of business innovation.

At the close of the 1920s, the world's aircraft manufacturers — there were a lot of them then — were all pursuing the same goal: building a faster airplane. With passengers clamoring for quicker flights, every manufacturer knew that a breakthrough in speed would spur big orders from airlines and other buyers, bringing them immediate riches. They also knew that most of the technological innovations required to construct faster aircraft had already been accomplished. Engines were powerful enough, fuselages were light enough, and steering and navigation systems were precise enough. The holy grail of faster flight was almost in hand.

But not quite. Progress was being held up by one of the oldest and most mundane of all the technologies used in aircraft: the wheel. A plane's landing gear had always hung in a fixed position beneath the fuselage or the wings. Because of its simplicity and accessibility, the rigid external gear was easy to maintain, and it was generally reliable and safe. But the bulky apparatus had a drawback: it created a lot of wind resistance. That had never been a problem when planes flew at relatively slow speeds, but as manufacturers tried to achieve higher velocity, the drag created by the wheels became a very big problem. The next leap in air speed would be possible only with a much more streamlined landing mechanism.

It was obvious to everyone that there were two possible solutions to the problem: Either improve the aerodynamics of the traditional fixed gear or figure out a way to retract the gear into the body of the plane between takeoff and landing.

Illustration by Lars Leetaru

In theory, retractable gear was the superior approach because it would eliminate the drag altogether. In practice, however, it didn't work very well. For one thing, it was hard to find space within planes to fit the wheels. For another, the gearing and motors required to retract the wheels were heavy and clumsy. Hydraulic systems would have been an attractive alternative, but at the time they were prone to failure. Because the cylinders could not be sealed tightly, hydraulic fluid tended to leak out, which not only increased maintenance costs but made landings riskier. Engineers could not be sure the wheels would actually descend when they were supposed to.

Despite the flaws in retractable gear, many manufacturers continued to tinker with the concept, hoping they could work out the bugs. But John Northrop, whose eponymous company was a leader in aircraft design, took the alternative route. Believing that the best solution was simply to streamline the existing gear, he invented a particularly elegant metal sheath that could be wrapped around a plane's wheels. It didn't eliminate wind resistance, but it reduced it enough to boost flight speeds another notch. And it gave planes a sleek, stylish look that appealed to pilots and passengers. By the mid-1930s, it appeared that Mr. Northrop had made the smart choice. His popular sheathing system seemed likely to win out over retractable gear.

Then, in 1937, a 72-year-old inventor named Niels Christensen invented the O-ring, and that changed everything. A thin, circular piece of rubber that fit into a groove on a metal fitting, the O-ring provided a leakproof but flexible seal for hydraulic systems. The tiny gasket proved to be a revolutionary innovation, making it possible to design a simple, reliable, and lightweight mechanism for retracting landing gear, and it opened the way to much faster flights. By the end of the decade, retractable gear was routinely being installed on planes. Far from being the victor in the technological contest, Mr. Northrop's sheathing had become obsolete.

The tiny O-ring gasket proved to be a revolutionary innovation, making possible much faster flights.

Reverse Salients

As John Campbell pointed out in a 1996 article in the journal of the Federal Reserve Bank of Boston, the landing gear of the early 1930s, before the O-ring was introduced, is an example of a "reverse salient." That odd term has its origins in descriptions of warfare, where it refers to a section of an advancing military force that has fallen behind the rest of the front. This section is typically the point of weakness in an attack, the lagging element that prevents the rest of the force from accomplishing its mission. Until the reverse salient is corrected, an army's progress comes to a halt.

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Historian Thomas P. Hughes was the first to apply the term to the realm of technological innovation. As described in his book *Networks of Power: Electrification in Western Society, 1880–1930* (Johns Hopkins University Press, 1983), a reverse salient often forms as a complex technological system advances: "As the system evolves toward a goal, some components fall behind or out of line. As a result of the reverse salient, growth of the entire enterprise is hampered, or thwarted, and thus remedial action is required." In technological advance as in warfare, the reverse salient is the weak link that impedes progress.

Such obstacles can arise in any kind of technological system, whether its focus is a product like an airplane or a process like the management of a supply chain. Reverse salients should thus be a critical concern of managers and entrepreneurs, particularly given today's tightly interconnected and technologically complex world of commerce. On the one hand, reverse salients present enormous business opportunities. A huge amount of economic value can get stuck in the bottlenecks that the salients form. By being the first to solve a given problem, a company can create a lucrative new market — and then grab the lion's share of it. As Professor Hughes notes, "Outstanding inventors, engineers, and entrepreneurs usually have a record of defining and solving such problems since remedying them can unlock a vast amount of value."

On the other hand, reverse salients also present big risks to innovative enterprises, particularly large, well-established companies. As John Northrop discovered, even a seemingly small innovation at the point of a reverse salient can quickly and dramatically alter the course of a technology, upsetting the status quo, changing customers' needs and expectations, and turning successful products into also-rans. That danger is magnified by the fact that reverse salients can be easy to overlook. As people become accustomed to a particular product or process, they often begin to take its flaws for granted — and hence become blind to the possibility for improvement. That's especially true of people who had a hand in creating a prevailing system and thus have a direct stake in its perpetuation.

Even Thomas Edison couldn't recognize that one of his core technologies — direct current — was a reverse salient.

Even Thomas Edison, the greatest American inventor of all, fell victim to this affliction. When, in the late 19th century, he pioneered the utility system for distributing electric power, he came up with brilliant solutions to a series of reverse salients that were hindering the design of lightbulbs, wiring systems, generators, and so on. But he became so enamored of his own system that he didn't realize that one of its core technologies — direct current — was itself a reverse salient. Because direct current could only be transported short distances over wires, it set a limit on the size and scale of early utility plants and prevented the next technological leap in power distribution. When Nikola Tesla invented motors that could run on alternating current, which had no such transport limits, he broke through the reverse salient at the heart of Edison's system. Edison's archrival, George Westinghouse, quickly bought Tesla's patents and used them to construct the alternating-current grid that, to Edison's dismay, became the dominant electricity distribution system.

How do you prevent such blindness? The best way is simply to maintain an open mind. But that, as Edison came to realize, is much easier said than done. Psychologists have shown that people have a natural bias to assume that the status quo will continue, particularly if they helped construct it. Most people are not naturally inclined to look for indicators of disruption in systems they consider adequate. There are some straightforward ways to counter this bias, though, and they all involve seeking out and paying attention to independent sources of information. Because reverse salients represent the most puzzling technological challenges, they tend to attract the interest of scientists and inventors. By keeping track of academic research and patent filings related to your area of business, and watching for patterns in the work, you can often spot reverse salients and begin to see different ways they might be solved.

Market research can also help. If buyers begin to express frustration or disappointment with a particular component or feature of a product or service, it's often a good indication that a reverse salient is forming. Consider the powerful server computers that run corporate software programs. Traditionally, the primary concern about these machines was their sheer data-crunching power. Buyers wanted the highest possible performance, so manufacturers concentrated on solving reverse salients related to processor clock speed and data caching. A couple of years ago, though, a handful of companies began to express concerns about the growing amount of money they were spending on electricity to keep their servers running. Those initial complaints provided an early warning for what has now emerged as a major reverse salient in server technology: power management.

Important insights can be gleaned from cost data as well. As Thomas Hughes observed, "Economy and efficiency — the first cherished by managers; the second, especially by engineers — also give direction to the movement of a system." By analyzing the economics of a product or a process, one can often pinpoint components or connections with disproportionately high costs. They may well turn out to be reverse salients.

Solving one problem in a complex system almost always brings another one to the fore.

Open or Closed?

Identifying a reverse salient is half the challenge. Fixing it is the other half. Here, companies can take one of two completely different approaches, which can be characterized as "closed" and "open."

In the closed, or proprietary, approach, a single company or individual takes responsibility for overcoming the reverse salients in a system and perfecting its operation (at least until new reverse salients appear). Edison took this route with the creation of the electric utility. He constructed the entire system, from dynamo to lightbulb, in his Menlo Park laboratory, assigning staff scientists and engineers the task of solving various reverse salients. More recently, Apple Computer Inc.'s Steve Jobs used this approach in creating a system for distributing and playing digital music. Although Apple drew on many outside suppliers for components, it maintained tight control over the entire system of software and hardware. In the process, it addressed numerous reverse salients in such areas as miniaturization, user interface design, file compression, and digital rights management.

The closed approach works particularly well for creating a new system from scratch. By keeping the construction of the entire system in-house, a company learns from direct experience where all the reverse salients lie. And because the solution to a reverse salient in one area of a system often requires changes to many other components, a single company can perfect the system much more quickly and efficiently than could a diverse set of actors working on individual components in a piecemeal fashion.

The closed approach does have drawbacks, however. For one thing, it's very hard to pull off. Because it requires unusual levels of organizational discipline, it's the kind of effort that rarely succeeds without a strong, visionary, and even monomaniacal leader — without, in other words, a Thomas Edison or a Steve Jobs.

Also, no matter how talented a company's staff, there will always be limits to its perspective and ingenuity. It may overlook — or mistakenly dismiss — alternative solutions, or it may solve one reverse salient only to create another. Edison's utility system was a work of genius, but in ignoring the benefits of alternating current, the Menlo Park team made an error that, in the end, proved fatal. Monomania has a price.

With an open approach, a company looks outside its walls for solutions to reverse salients. It's an approach that can work particularly well for enhancing an established product or service — for overcoming a particular, well-defined obstacle that's impeding progress. The owners of the Liverpool and Manchester Railroad used an open approach to great effect in 1829, just before they completed the construction of their 32-mile line. At the time, trains rarely went more than 10 miles an hour, making them little faster than horse-drawn carriages. Eager to recoup their big capital investment in the new railroad, the owners were desperate to enhance rail transport's attractiveness by increasing its speed.

The reverse salient in the railway system lay in the design of steam locomotives. Locomotives were unable to sustain high speeds without breaking down. Instead of trying to fix the problem themselves, which would have been costly and risky, the owners decided to let others fix it for them. They organized a competition among locomotive manufacturers along a two-mile length of track in the town of Rainhill, near Liverpool. Each manufacturer could enter a locomotive, and whichever engine completed 20 round-trips on the track in the shortest time would win a prize of £500 — and could also expect a lucrative contract for supplying the locomotives used on the line.

The contest, which received a great deal of publicity from the English press, spurred a burst of innovation in engine design. The engine that won the competition, the Rocket, was able to top a speed of 30 miles an hour on the course. By tapping into the skills of a broad set of outsiders, the operators of the Liverpool and Manchester Railway were able to quickly overcome a debilitating reverse salient — and secure their business's success.

Today, with global communication systems like the Internet, the open approach can be applied more broadly and more powerfully than ever before. The entire open source software movement, for instance, is founded on the ease with which a huge number of coders can identify and rectify reverse salients in complex software programs.

Eli Lilly and Company is pioneering a similar model for corporate research and development. In 2001, it launched a Web site called InnoCentive that allows companies to list problems that they need to have solved along with the reward that they'll pay for solutions. Any scientist anywhere in the world can then work on the problem. Whoever discovers the answer gets the bounty. Some 100,000 scientists have signed up to contribute solutions, and companies as diverse as Dow Chemical and Colgate-Palmolive have found valuable innovations through the site, including a better way to incorporate fluoride into toothpaste. In a very real sense, InnoCentive creates a market for solving reverse salients. If it had been around 80 years ago, the O-ring might have come along much sooner than it did.

The open approach can correct a reverse salient quickly, but it, too, carries a price. By giving up control over a solution, a company may also sacrifice the financial rewards the solution generates. And because reverse salients can be so important to technological progress, those rewards may be quite large. Open source software development, for example, has proven to be an effective method of continually enhancing existing programs, but it also risks sucking profits out of the programs themselves and shifting the money toward related services, such as maintenance.

Whether an organization takes an open or a closed approach to addressing a reverse salient, solving one problem in a complex system will almost always bring another problem to the fore. The barrier to progress, in other words, will simply shift to the next weakest component or technology.

The wisest companies don't just ask, What's the current reverse salient in the system? They also ask, Once this problem has been solved, what will become the new reverse salient? It's the same question that the smartest generals ask as they lead their forces into battle. ✚

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