

Is the Information Revolution Dead?

If history is a guide, it is not.

By W. Brian Arthur

At the peak of the Internet frenzy two years ago, when the Nasdaq was over 5,000 and dotcom millionaires were buying spreads in the hills above Palo Alto, it seemed that the information revolution would go on forever. Little tech companies were popping up everywhere, and small investors were reaping returns that made them feel like geniuses. Then the bubble burst. It burst, management guru Peter Drucker tells us, because "the information industry as a business wasn't going anywhere." The information revolution had been hyped, exaggerated. Neither computers nor the Internet, Drucker says, had added much to the economy.

Is the information economy going nowhere? Is its revolution over? In Silicon Valley, certainly, the prospects look bleak. But history suggests that such pessimism is misplaced -- that the information revolution's best days might actually lie ahead.

Looked at *without* historical context, the information revolution appears to be unique, comparable to nothing we know about from before. Looked at as part of history, it is merely one in a series of technological revolutions that have been occurring since the mid-18th century. Each of these revolutions has been different: The Industrial Revolution, from about 1760 to 1820 in Britain, replaced handcrafting with machinery and brought the factory and mill system. The railway revolution, from about 1825 to 1875, again in Britain, saw a great connecting of commerce and the coming of steam power. The steel and electricity revolution, from about 1875 to 1920 (the action now shifts to the United States and Germany), was an age of massive engineering and the electrification of the economy. The great manufacturing age, from 1910 to 1970 or so, brought us mass production and automobiles and cheap goods aplenty. And our own revolution, which started with the microprocessor in about 1970, brings us the age of digital everything, the Web, and interconnected commerce. The dates I've given are approximate. Economists quarrel over when such eras started and ended, and about which clusters qualify as "revolutions." Some deny that "eras" of great change exist at all. Others, notably economists such as Carlota Perez and Chris Freeman of the Sussex school in England, champion the notion of revolutions and see in their phases portents of what is to come.

All threads of thought on technology revolutions lead back to Austrian economist Joseph Schumpeter, a single figure writing in the first half of the 20th century. Schumpeter has a curious position in economics. He is revered on the continent of Europe, yet has a shadowy reputation in Anglo-Saxon economic circles -- you can get a graduate degree in economics at an English or American university and scarcely hear of him. He is remembered more by business gurus for his idea of innovation bringing "gales of creative destruction." Professors who do speak of him are fond of telling their classes that Schumpeter aspired early in life to be the greatest economist in the world, the greatest horseman in Austria, and the greatest lover in Vienna. The story smacks of myth. But as far as I can track it down, it is true, and late in life Schumpeter is said to have only admitted that he was not the greatest horseman in Austria. Was he the greatest economist in the world? He was certainly not considered so during his lifetime -- others, his nemesis John Maynard Keynes among them, were better known. But I believe that Schumpeter will turn out to be the most important economist of the 20th century. He concerned himself not with an economy at rest but with the unfolding of economies, with their ongoing tendency to evolve and develop and change in structure. And this he ascribed to innovation -- to ongoing, disruptive discoveries in technology and their incorporation in the economy. His writings, some now nearly 100 years old, are surprisingly modern.

Schumpeter noticed that technology arrives in clusters -- with electrification come dynamos, generators, transformers, switch gear, power distribution systems; with mass production and the automobile come production lines, modern assembly methods, "scientific management," road systems, oil refineries, traffic control. These clusters, if they are important, define an era. They eventually change the way business is done, even the way society is conducted. As Perez tells it, a technology revolution starts with the opening up of one or more technologies that "enable" the new cluster. The new technology cluster,

at first little noticed, achieves successes in early demonstrations, and technical people start small companies based on the new ideas. These compete intensely in this early turbulent phase. Government regulation is largely absent, and as successes mount in a technical free-for-all, the promise of extraordinary profit looms. The public starts to speculate. (In the mass-production revolution, think of the 1920s in the United States.) The middle phase sees a sustained buildout or golden age of the technology, during which it becomes the engine of growth for the economy. Large companies and oligopolies reign, and the period is one of confidence and prosperity. (Think of the 1950s and '60s.) In the last phase, the technology is mature. It has saturated its possibilities, production moves to places on the periphery, and complacency sets in. (Think of the 1970s and the rise of competition in Japan and Taiwan.) Profits at home are low, and entrepreneurs begin to look around for new opportunities. The economy becomes ripe for the next revolution.

The exact phases and what happens within them are debatable. But what interests me is the pattern of speculative exuberance, followed by crash, followed by a strong buildout period. If the Schumpeter-Perez-Freeman story holds water, we are not at the end of the information revolution. We are only partway into it, and the buildout -- the golden age -- has yet to come.

If we lay the information revolution alongside the great railway revolution in Britain, year for year, we'd now be somewhere around 1850 -- just after the railway investment mania of 1845 and its crash in 1847. The railway revolution took place roughly between 1825 and 1875. I say roughly, because there never is a marked beginning or end to an economic revolution. Even in 1825, railways were by no means new. For centuries, mines had used horse-drawn wagons to move ores on wood or iron-capped rails. The first commercial railway, the Stockton & Darlington, owned a single locomotive when it opened in 1825, and its Express was still a carriage drawn on rails by a cantering horse. Even when the Liverpool & Manchester Railway was being planned in 1829, its directors doubted that a moving locomotive could retain adhesion on uphill gradients. The conventional view bet on carriages hauled by ropes attached to stationary winding engines. In October 1829, the L&M organized a locomotive trial at Rainhill, stipulating that the engine must be capable of "drawing a train of carriages at 10 mph." Five locomotives entered, and Robert Stephenson's Rocket astonished the watching gentlemen by achieving 24 mph unloaded and 12 mph hauling a train up the Rainhill incline. Locomotives had proved themselves. Technical pioneers began to crowd in, a host of improvements followed, and a decade and a half of frenzied technical competition was under way.

The new technology engendered talk of a new, more prosperous economy. An 1831 prospectus for the London & Essex Railroad promised that "the first necessities of life will be supplied in greater abundance; competition increased, and a reduction in prices the necessary consequence." Railways became fashionable. Queen Victoria made her first railway trip in 1842 in a suitably imperial carriage and allowed that she was "quite charmed by it." Entrepreneurs began to emerge, among them George Hudson, the "railway king." Hudson started as a draper in York, inherited money, and found he had a talent for putting together new and branch lines. He became a public figure, fawned over, known as His Steam Majesty. A contemporary observer, John Francis, recorded that "his fortune was computed with an almost personal pride.... The choicest aristocracy ... sought his presence.... The bishop bent in homage.... When his name graced an advertisement, men ran to buy the shares. He was their railway potentate; their iron king; their golden god." The railway kings such as Hudson were not so much technical people as organizers and investors -- mainly of other people's money. And indeed they organized and invested. And got rich. They bought large estates -- Hudson purchased the magnificent 100-acre Newby Park estate from Earl de Grey in 1845.

Hudson was one of many railway entrepreneurs. The procedure in proposing a railway required bringing a bill before Parliament; if it was approved, the stock could be subscribed in a sort of Victorian IPO. Gentlemen and politicians and dignitaries such as the Duke of Wellington bought stock. Those who could not afford stock could buy scrip -- shares diced and parceled into small units that could be sold on the street. Servants and spinsters and tradesmen began to pour their savings into railway scrip.

By 1845 a full railway mania was raging. By the summer new schemes were being floated at the rate of more than a dozen a week. Scrip was sold by alley men, and the stock exchange resembled a country fair. The general prosperity contributed. "The markets were good ... and all was smiling," Francis wrote. "The most cautious were deceived by this apparent prosperity.... Like drunken men they lost their caution and gave their signatures to everything that was offered.... Many of the railways attained prices which staggered reasonable men. The more worthless the article, the greater seemed the struggle to attain it." Schemes for direct lines connecting little-known towns to other little-known towns became a craze, launched more with an eye to garnering investment than actual profits. "The country," said Lord Cockburn, a Scottish judge, "is an asylum of railway lunatics." Not all schemes could be profitable. "We see nine or ten proposals for nearly the same line, all at a premium, when it is well known that only one CAN succeed," said the Economist. The result, predictably, was overcapacity. There were three independent routes from London to Peterborough, and three from Liverpool to Leeds.

Trouble began in October 1845, when scrip ceased to pay a premium and shares in established railways began to fall. Great Western Railway shares had plummeted 40 percent from their August peak. A harvest failure in 1846 compounded the downswing, further bankruptcies followed, and an economic Week of Terror began on Monday, Oct. 17, 1847. Some banks were forced to close. The Bank of England held less than £2 million in reserves, and special measures had to be taken to stave off national economic collapse. When the panic was over, railway shares had lost 85 percent of their peak value and several hundred companies had folded. As Francis recorded it, "Entire families were ruined. There was scarcely an important town in England but what beheld some wretched suicide." Hudson himself was never convicted of wrongdoing. ("He was obviously no adept at the higher arts of swindling," Schumpeter remarked.) But he was now a pariah and fled to Paris. Thomas Carlyle wrote in 1850 of imagining Hudson swinging on a gibbet "as a tragic pendulum ... veritably the Supreme Scoundrel of the Commonwealth, who in his insatiable greed and bottomless atrocity had ... led multitudes to go, in the ways of gilded human baseness; seeking temporary profit ... where only eternal loss was possible." Many of Hudson's investors cherished a similar hope.

Fifty years earlier a similar story had played out in the canal mania of the 1790s. Canals had been around for a couple of hundred years, but got under way seriously in Britain in 1761 when the Duke of Bridgewater drove a canal from his coal mines at Worsley to the textile mills at Runcorn. In the two decades that followed, large profits from this and similar undertakings brought about the swift expansion of canal systems -- and a speculative mania in 1792. Canal shares crashed in 1793, to the ruin of many.

What is interesting about both the canal and railway revolutions is that their crashes were by no means the end. In the decades after 1793, Britain went on to build out 2,000 miles of waterway, doubling its precrash mileage. And canals became the key infrastructure component of the Industrial Revolution. Similarly, in 1845, just before the crash, Britain possessed 2,148 miles of railway; 65 years later it had 21,000 miles. The major buildout of railways came *after* the crash of 1847.

Of course, after a crash much of the glamour of the new technology is lost and is not easily replaced. The new period is different. The mood is different. If the period before 1847 is a time of excitement and of small companies jostling for dominance, the years after 1847 are ones of seriousness and hard work -- years of buildout rather than novelty, years of confidence and steady growth, years of orderliness. Investment profits begin to reflect the real returns from the new technology. The base technology is now in place, but before the crash it had not accounted for much in economic terms. In the decades following the 1847 crash, the railways come into their own. Passenger and freight receipts become multiples of what they were before, and the very growth of the railways helps the economy to grow, which further stimulates the railways. After 1850, railways become the engine of the economy in Britain.

In the United States, there was no equivalent of the British railway mania. Certainly there were periods of setback in which railroad overinvestment was partly to blame. In the depression of 1859, the economic commentator Henry Carey Baird complained that "our railroad system has cost more than \$1,000,000 and has brought ruin upon nearly

everyone connected with it, the nation included." But, again, at this time railroads in the United States were just beginning. In 1860 the United States had 30,000 miles of built-out track; by 1914 it had 253,000 miles. The buildout, when it came, was massive. And it brought an age of oligopolies and railroad barons. Yet in spite of such excesses, railroads became the driving force of the U.S. economy. Railroads opened up the West, they provided demand and thus the base for the new steel industry, they made possible new commerce and other new industries, they brought new cities and centers of population into existence, and as in Britain the commerce of the country organized itself around them.

Not all technology revolutions of the past exhibit manias and crashes. Economists dispute to what degree the great crash of 1929 was the result of overexuberance about the stocks of the new automobile manufacturers and other mass producers. And there was no steel crash in the 1890s. But this dog-that-didn't-bark clue -- the absence of a steel crash and dubiousness of a mass-production crash -- doesn't negate any correlation between the railway crash and the Internet crash. It points to a resemblance that might otherwise be missed. Railways and canals, like the Internet, are *connection* technologies. They connect places, they connect businesses. As such they are natural monopolies -- only one line, or one canal, can profitably connect Liverpool to Manchester, and once this is put in place, competing lines lose. For connection technologies, this brings on a "race for space." And this in turn means that when the opportunities open up, they open not with an orderly funding but with a heated sense that they are finite and will soon be filled. The result can easily be an investment frenzy -- a mania. By contrast, steel factories can constantly improve and undercut one another, so that as the technology improves in an orderly way, it becomes financed in an orderly way. No mania. But with or without manias, all revolutions still progress from early chaotic innovation to buildout, and then to tired overcapacity and foreign competition.

The current technology cluster -- microprocessors, telecommunications, software, the Internet -- has had its boom and crash. And as with the railways, the telecommunications side of it suffers from overcapacity. It has made possible a host of subtechnologies and digitally based activities -- genomics, CT scanners, DNA probes, global positioning systems, cell phones -- and nobody doubts that it will spawn others. But the Internet part of this revolution seems to be in trouble and its prospects are derided. Is its buildout yet to come? Certainly we can match the Internet with what happened in the 1840s: the initial successes, the ballyhoo, the IPO kings, the large estates. And the crash. But an eerie resemblance to events of 160 years ago doesn't guarantee that the information revolution is about to enter any golden age. What evidence is there for this?

One argument I don't buy is the proposal that the information revolution has been around long enough to have had its chance. Its enabling technologies -- the laser, the microchip, the Arpanet (forerunner of the Internet) -- date from the 1950s to the early 1970s. So the revolution, this argument goes, has had 30 years to prove itself and we have yet to see its economic gains. Here again, history tells us otherwise. It tells us that a considerable delay -- several decades, usually -- lies between the technologies that set a revolution in motion and the revolution's heyday. The enabling technologies of the steel and electricity revolution (the Bessemer steel plant and the electric motor and generator) had arrived by the 1870s, but their full effects were not felt until well into the 1910s. Watt's steam engine was developed in the 1760s; steam power did not come into prevalent use until the 1820s. Modern mass production arrived in 1913, but did not reach its peak until the 1950s and '60s. Such decades-long delayed reactions should give us a clue that something other than the appearance of a technology and its subsequent adoption is at work. If a powerful new technology appears, it might take people a decade to hear about it and try it. But three decades? Five decades? Something else besides slowness to glom onto the new technology must be going on.

That something else, I believe, is that many arrangements, many improvements, and many organizational changes need to be put in place before the new technology cluster can become widespread. It is not enough that the base technologies of a revolution become available. Whether these are railroads or microchips, a revolution doesn't fully arrive until we structure our activities -- our organizations and business methods -- around its technologies, and until these technologies adapt themselves to *us* by becoming comfortable and easy to use. So it's not merely that the base technologies have to become

better, faster, cheaper. That helps, but what's needed for the revolution to fully blossom are the 1,001 subtechnologies, arrangements, and architectures that adapt us to the new technologies and them to us. Their arrival takes time, and it defines the buildout period as one that creates the arrangements and subtechnologies that bring the new possibilities into full use.

We can see this with railways after the crash of 1847. Not only did rail transport become better, faster, cheaper -- with improvements such as steel rails arriving in the 1860s and, a decade later, compound locomotives that increased power by expanding steam in one cylinder after another. But systems that made railways usable and safe -- what I will call arrangements-of-use -- also followed in this period: lever systems that worked switches and signals, control of traffic via the electric telegraph, air brakes, double tracks, Pullman sleeping cars, dining cars, toilets. (Toilets arrived later on British trains than on American ones due to a certain English indisposition to admit bodily functions in public.) In the buildout period, innovation continues adapting the new technology to human use without letup. And business in turn adapts itself to the railway. Factories that might formerly have been located near rivers are now for convenience located near railways. Production facilities and shipping methods are adapted to the new transportation.

In fact, with any important revolution, business organization needs to do more than adapt. It needs, to some considerable degree, to redefine itself -- to re-architect itself. In 1955, economist Marvin Frankel noted that England's Lancashire textile mills still used old, out-of-date machinery. Yet the mill owners were aware of the advantages of modern methods and machinery. Why didn't they adopt them? Frankel found that the new, more efficient machines were heavier and larger, and the old Victorian brick mill buildings with their close supporting columns could not physically accommodate them or bear their weight. The new technology required tearing down the old structures and building different ones. The costs of this were prohibitive. Economic historian Paul David tells a similar story about the slow adoption of the electric motor. Before electrification, every factory was powered by a single steam engine, a giant hissing and cranking contraption with pistons and a flywheel and a system of belts and pulleys that turned shafts on several floors of a building to power all of the factory's machinery. Electric motors powered machines separately, and therefore often required factories to be redesigned. Industrial architects knew nothing of electricity, and finding the proper layout and organization took much experimentation. Full adoption took 40 years.

We are in a similar position today with computation and the Internet. Businesses routinely install digitally based equipment or enterprise software or peer-to-peer communications. But for effective use, they need to restructure their activities -- their very organization. How to do this, exactly, is not yet known. Businesses don't know what the appropriate organization will look like, and they face the possibility that any reorganization may well be quickly outdated by new technologies. Even if the correct organization were known, businesses would still have to pay the Marvin Frankel costs of tearing down the old structures. Much of the technology is available, but its use requires a slow process of learning and investment. In fact there is strong evidence that just such a process of tearing down old structures and steadily adopting information technology was under way in most U.S. industries all through the 1990s and that it statistically accounted for virtually all of the considerable productivity gains of that decade. Two recent studies show that this process continues -- that even after the recent crash, productivity gains issuing from the new technology have barely slackened. The reason is simple: Crash or not, information technology prices fall constantly, and businesses take advantage of this to purchase the new technology and adapt their methods to it.

This is healthy. But it is not sufficient that businesses and people adapt to a new cluster of technology. The real gains come when the new technology adapts to *them*. The notion that a technology needs to adapt to its users seems obvious enough, but is heavily underestimated. People will not use a technology that doesn't work properly. They will shun anything awkward or untrustworthy or just plain difficult to use. Making the technology better, faster, cheaper is only part of what's needed. A new technology is used when it is more convenient, easier, reliable. For widespread use, a technology must provide, in a word, amenity.

As technologist John Seely Brown points out, something subtle happens to a technology when it achieves amenity: It disappears. We become absorbed into its world, and its bones don't stick out anymore. Thus, if we are driving a car at night, we are absorbed into car-world -- we are aware we are driving, aware of the passing trees and fences, but not aware of the car as a technology. The car disappears. By this standard the Internet is somewhere around the get-out-and-get-under days of the Model T Ford. To access my bank account, I have to fire up my computer, and wait. Then dial in by modem, and wait. Then get a browser going, and wait. Then enter account numbers and passwords, and wait. All the time there exists a barely noticeable anxiousness that the process may hang up at any moment. The Web's interface remains uncomfortable to use: ill-fitted, unreliable, frustrating, slow, and lacking content when we get there. It has not disappeared, nor has it achieved amenity. It will take time for amenity technologies to become available and used. It took automobiles from about 1890 to the 1940s -- half a century of development -- to reach amenity. Needed were paved roads, reliable brakes, ignition systems, safe tires, and a thousand other things.

The information revolution is not radically different from previous revolutions. The Internet has had its boom and crash, and there is no reason to suppose that history will be negated: Full use of the technology will arrive eventually. It always has. But this will require that the technology become workable for the user, and that businesses re-architect themselves to make use of it. This will happen gradually during the next 10 to 20 years as the missing components of the technology's use structure are put in place. In this buildout, the technologies that will matter most, that will determine the pace, are the ones I am calling arrangements-of-use. If there is one difference with this revolution, however, it is that it won't end when we have blanketed the country with optical cable or have teraflop processors. Information technology morphs every 10 years or so, so that what we thought defined the information revolution -- batch processing, desktop computing, Web-based interconnection -- is continually superceded by something new. What lies ahead can never be fully foreseen. This means that we can expect *more* innovation in this buildout phase than with previous revolutions. But during the next few years, at least, what will drive the buildout is something at once silent and unremarkable: the quiet, inexorable interconnection of business and the slow appearance of Web-based services that digitization provides.

How fast can the information technology economy come back? I don't know. The economy is quiet now, gestating a new phase. What I do know is that when that new phase comes forth, it will be a giant.