Tracks That Changed the World

Almost two centuries ago, railroads altered the commercial and social course of the world. Although often overlooked, they are still responsible for much of the global economy.

Story by Mike Field

They were the defining technology of the 19th century. They form the backbone of modern industrial society. They will become the energy-efficient, low-emissions transport systems of the future. And chances are, they rumble by regularly within only a mile or two of your own front door.

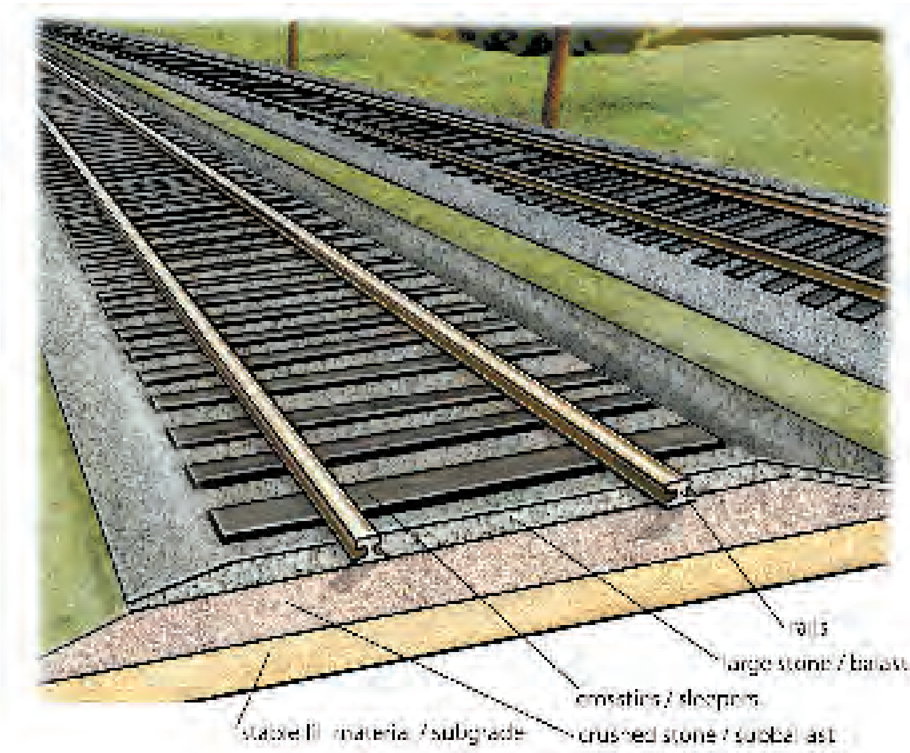
They are the railroads, mighty movers that transformed the modern era.

While recently the world's attention has been focused on computing power and gigabytes, baud rates and bandwidth, the railroads have been quietly going about their business, improving their engines, upgrading their tracks, and steadily advancing their capabilities. The system of rail lines that knit together society beginning in the 1830s is poised to hold together the high-speed global economy of the 2030s—and beyond. Yet ironically, few people today give the railroads a second thought.

"People underestimate how important they are," says Christopher Barkan, director of the Railroad Engineering Program at the University of Illinois at Urbana-Champaign. "The fact is, our society couldn't function without the railways."

The U of I campus is home to the largest railroad engineering academic program in North America, one of a handful of research centers worldwide that are inventing the train systems of tomorrow. Some of those trains are already here.

Yet the basic configuration of railroads—a locomotive pulling or pushing linked cars on a track of parallel rails—



still looks much the same as it did 150 years ago. Those outward appearances are deceiving, however. Almost every facet of the railroad industry has advanced dramatically in the past two decades. From roadbeds and rails, to locomotives and cars, the railways of the 21st century employ advanced technologies that would make them almost unrecognizable to the legendary personalities who invented, built, owned and ran the railroads of the 19th century.

Speed and Efficiency

Innovations in 21st-century railroading are largely focused on safety, increasing speed and improving efficiency. But that has been what railroads have always done best, since the first commercial rail line began carrying both passengers and freight between two English cities—Liverpool and

ILLUSTRATION BY TADEUSZ MAJEWSKI.

Manchester—on September 15, 1830. That date is where some historians draw a line to separate the modern era from all history that came before.

In many ways, the world just prior to trains was little changed from the time of Julius Caesar. In those days, towns and cities were almost always located by a major waterway, since boats and barges were the most efficient form of transport. Over land, a man could go no faster than a horse could run—and then only for short distances. The great majority of people never ventured farther than a few miles from their place of birth. News traveled only as fast as the speediest riders were able to carry it.

The inaugural excursion of the Liverpool-to-Manchester railway was the catalyst for change. The steam locomotives of those days were underpowered and slow, typically averaging just 12 to 15 miles per hour; soon the railroads would regularly sustain overland speeds of 30 mph or more, while carrying ever-larger loads of people and freight. By the middle of the century, they could travel a mile a minute. The modern era had indeed begun.

Now, increasingly, people would travel and work ever farther from home, and make those journeys at ever faster speeds. The range and quantity of goods and services that could be traded quickly and at low cost exploded. Prior to the completion of the first transcontinental railroad in North America, a journey from New York to San Francisco took an arduous six months and cost what was then the hefty sum of $1,000. After the golden spike linking the east- and west-bound rail lines was driven home on May 10, 1869, the same trip took just seven days—and cost $70.

It's All in the Wheels

"Our industry is always looking for better ways to move things," says Mark Davis, spokesman for Union Pacific, one of the oldest and most famous North American railroad corporations. "As a result, there is a near constant change and advancement in the technology we employ."

Yet for nearly 200 years, the fundamental characteristic of a railroad has remained the same. A railway is a mode of transportation in which locomotives and passenger- or freight-carrying cars ride, and stay on, parallel steel rails thanks to a flange, or lip, on their steel wheels. This is the secret that gives trains their unmatched capacity to provide low-cost, heavy-duty transportation. The flanges (which are on the inside of the wheels) guide the train cars and locomotives on the track, creating a self-steering form of transport. The loss of independent steering is more than

Railroad Milestones

1804 – British inventor Richard Tevithick invents the steam locomotive. It runs on iron rails and successfully hauls 10 tons of iron 10 miles.

1814 – British engineer George Stephenson introduces the first steam locomotive, capable of hauling 30 tons at speeds faster than possible with a horse-drawn system.

1828 – Charles Carroll, last surviving signer of the Declaration of Independence, lays the first stone for the Baltimore & Ohio Railroad – the United States' first chartered railroad.

1830 – The Liverpool and Manchester Railway in England becomes the first regularly scheduled steam-driven railway to carry both passengers and freight.

1862 – Former railroad lawyer Abraham Lincoln signs the Pacific Railway Act, authorizing the construction of the first transcontinental railroad.

1868 – The knuckle coupler, which allows rail cars to be joined without putting a rail worker between cars, is invented by Eli Janney.

1869 – The air brake, which automatically applies braking pressure on every car attached to a locomotive, is invented by Union Army veteran George Westinghouse.

1869 – The first transcontinental railway link, uniting California to New York, is completed with the driving of the golden spike at Promontory Point, Utah.

1871 – The 13.7-kilometer Mont Cenis Tunnel connecting France and Italy opens. It took 14 years to build and was twice the length of the world's longest tunnel at that time.

1885 – The first transcontinental rail link across Canada is opened.

1917 – The era of steam begins to end as the first diesel-electric prototype locomotive is produced.

1932 – Britain's Great Western Railway introduces 'The Cheltenham Flyer,' the world's fastest steam train, averaging more than 70 mph.

1964 – The Tokaido Shinkansen, the first of the famed Japanese 'bullet trains', opens between Tokyo and Osaka, running at speeds up to 125 mph and inaugurating the era of high-speed rail travel.

2005 – The Qingzang Railway, connecting China to Tibet, becomes the highest railway track in the world at 5,072 meters (16,640 feet) above sea level.

made up for by the measure of the rolling friction of steel wheels on steel rails, which is extremely low.

As a result, very large loads can be moved by rail with relatively little horsepower—about one horsepower per gross ton, compared to roughly 10 horsepower per gross ton for the typical tractor-trailer you see speeding down the highway. That's a 10-to-1 advantage in efficiency. Measured another way, a standard gauge 40-ton freight car set free at 60 mph on a flat railway would roll for five miles before coming to a rest. A motor truck of the same weight traveling the same speed on a level roadway, by contrast, would come to a stop after only about one mile.

To achieve these efficiencies, however, railroads must give up other things (such as steering) in return. Rail technology imposes certain limitations that never challenged the great road builders of the past. As a general rule, standard gauge railways must be nearly level, rising or falling by less than 4 percent, or four feet of height for every 100 feet of length. A major modern highway, by contrast, will sometimes contain grades of 10 percent (and secondary roads grades of twice that), since rubber wheels on hardened pavement have much higher rolling friction than steel wheels riding rails.

The rails are laid parallel 4 feet 8.5 inches apart, following the precedent of the pioneer Liverpool-Manchester line. Why 4 feet 8.5 inches? Wagons of the day had wheel spacings of this measurement because the ruts in Europe's older roads were about this space apart. Legend has it the measure actually dates back to the Romans for it is about the width of two horses pulling a chariot.

The train wheels riding on those tracks are fixed in a straight axis, which means that track must be laid as straight as possible, with changes in direction achieved by long radius curves measuring only a few degrees over 100 feet of track. A train, unlike a truck, cannot make a sharp turn to the left or right, or wind through a series of hairpin turns.

These requirements posed enormous challenges to the railroad builders of the 19th century, so it is no surprise that many of the technological marvels of that day were the bridges, tunnels and other structures that provided the roadbed on which to lay track. Conquering topography has always been the railroads' greatest challenge; once that is done, it is not particularly difficult to build a rail line.

First, a layer of natural soil or stable fill material is leveled and compacted to form a subgrade, and drainage ditches, culverts and other water-control systems are put in place to prevent washouts.

On top of the subgrade, a layer of crushed stone, called the ballast, is laid and smoothed in depths of one to several feet. Then a course of railroad crossties, or sleepers, are laid parallel to one another, transversely across the path of ballast. In North America, wooden crossties treated with creosote predominate; these are spaced 19.5 inches apart. In Europe and wherever wood is scarce, sleepers are now commonly made of reinforced concrete, which has a shock-absorbing pad to cushion the rails. These are spaced on 24-inch intervals.

At this point the ties are tamped and leveled to maintain a constant horizontal plane on which the rails are mounted. Metal plates that help distribute the weight on the rails more evenly along the ties are put in place, and the rails are then either spiked (for wooden ties) or clipped (for concrete ties) into place. Nowadays, rails are welded one end to the next in quarter-mile strings, and ground to a clean finish, creating a smooth and continuous ribbon of steel. After the rails have been completely fastened down, a "stone train," which dumps ballast from the bottom doors of specially designed ballast cars, is run over the new rails. Then a computerized tamping/lining machine moves over the track lifting it to the proper grade, lining it horizontally and compacting the stone under the ties—all in one operation. Finally, a ballast regulator plows and sweeps the track to clear out any stray ballast.

One of the unique characteristics of railroads is that the ties

Fast Trains

If you want to go really fast while still on the ground, you need to take a train. And for really fast trains, the place to go is France, where the TGV—in French, le Train à Grande Vitesse, meaning high-speed train—journeys between Lyon-St. Exupéry and Aix-en-Provence at a zippy 263.3 kilometers per hour (164 mph).

Not to be outdone, the Japanese—who invented high-speed train service with the creation of the fabled "Bullet Train" service between Tokyo and Osaka in 1964—currently run a Shinkansen (meaning New Trunk Line) train between Hiroshima and Kokua at 261.8 kilometers per hour.

And in what may be the train technology of the future, a German-built magnetic levitation (Maglev) train line linking downtown Shanghai to its airport 30 kilometers (19 miles) away opened in March of 2004. The train travels point-to-point in seven minutes, 20 seconds, at times reaching a breathtaking 430 kilometers per hour (267 mph). And that may be just a tick of the speedometer: in Japan, an experimental Maglev train recently recorded a speed of 581 kilometers per hour (361 mph), which begins to put trains in the speed range of conventional airplanes.

Freight transport is all about weight and volume—how much stuff can you haul and how often? But for passenger service, the mantra is: How fast can you go? As the 20th century gave way to the 21st, suddenly passenger train systems everywhere were pressing the pedal to the metal. According to Railway Gazette International's 2005 World Speed Survey, four countries now have regularly scheduled train service operating at average speeds of 200 kilometers per hour (roughly 125 mph) or above: France, Japan, Germany and Spain.

More countries are joining the club each year, and more lines are getting faster. France counts six routes that average 250 kilometers per hour (155 mph) or greater; Japan has three. The United States, which lags far behind in high-speed rail, now runs its Acela Express between Wilmington, Del., and Baltimore, Md., at 165 kilometers per hour (roughly 103 mph).

How fast will trains eventually go? In theory, at least, trains can go as fast as planes (indeed, at top speed France's TGV is going twice the speed of a 747 at takeoff) and the current rail vehicle speed record is a face-flattening 10,300 kilometers per hour (6,400 mph) set by an unmanned rocket sled at New Mexico's Holloman Air Force Base in April of 2003.

In reality, however, rail systems are limited not by the speed of their locomotives but by the design of their track way. At speeds of 150 kilometers per hour (93 mph) even curves of a radius of three miles start to feel uncomfortable for passengers (the high-speed Italian Pendolini trains overcome this problem by 'tilting' as they go through curves). In addition, signaling for train crossings and other technical issues tend to limit speeds. At present, only France, Japan, Germany, Spain and South Korea have track ways rated at 300 kilometers per hour (about 185 mph) or above.

Fast trains, from top to bottom: French TGV; Shinkansen bullet train (two photos); Shanghai Maglev train at station; test of Japanese ultra-high-speed Maglev train; the first U.S. high-speed train, Amtrak's Acela Express.

SHANGHAI TRANSRAPID PHOTO BY YOSEMITE; JR-MAGLEV PHOTO BY YOSEMITE; ACELA PHOTO © CIAN GINTY.

are not set in a rigid foundation; they 'float' on the bed of ballast, and as anyone who has stood near a passing freight train can attest, the ties and rails actually flex to a noticeable degree. This is how a comparatively lightweight roadbed can sustain continual traffic of cars weighing 143 tons pulled by 200-ton locomotives, while accommodating large fluctuations in temperature and weather.

The World Bank reports that traffic on the world's railways is extremely concentrated, with the top five national railway systems (U.S., Canada, former Soviet Union, India and China) carrying more than 90 percent of all railroad freight and 56 percent of the passenger load. For a modern economy, the right railroad in the right location can make all the difference.

"Basically, if you are looking for drivers of economic growth—things that increase wealth and drive down poverty—you want to support activities and investments that promote trade," says World Bank transport adviser Paul Amos. "Railroads can do this, but they need to be well-placed and well-managed."

Having a rail line in and of itself does not assure economic prosperity, as countless deserted towns along abandoned rail lines can attest. Says Amos: "There is a great difference between a railroad between two cities of 3 million inhabitants each in China, and a system that meanders through sparsely populated savannah in Africa."

Economic forces in recent decades have resulted in two kinds of railroads around the world: a highly efficient, slow to medium-speed freight transportation system as in North America, or a fast to high-speed (150 mph or more) passenger-carrying system as in Europe and Japan. "It really comes down to the question of whether the rail system is being run for profit—which means freight service—or for passengers and public service," says Amos. "Unfortunately, the two systems don't mix well together."

China, the world's fastest growing economy with the world's busiest railroad system, has had to confront this problem head-on. In the next 15 years, the Chinese plan to invest more than $200 billion in their rail network, and add 25,000 kilometers (15,500 miles) of track to the system. Part of that enormous investment will go to create separate passenger-only rail lines between major metropolitan centers, the first step in creating two rail systems, each with its own set of tracks and equipment. If history is any guide, it will be money, materials and manpower well spent.

Special thanks to Jim Smith for his assistance with this story. Mr. Smith is regional operations director for the Central Region of the Virginia Department of Transportation.

What's the Time?

One little-known but hugely important byproduct of the invention of trains was the standardization of time. In the years before the coming of the railroads—and for all human history up to then—time was strictly a local affair. A town or village generally set time based on the position of the sun relative to the area's tallest structure (often a church steeple).

Not only was this imprecise, but towns 50 or 60 miles apart on an east/west axis would naturally record the sun's apogee, high noon, at a slightly different time (owing to the rotation of the Earth). However, such differences were inconsequential when it took more than two days to travel 60 miles.

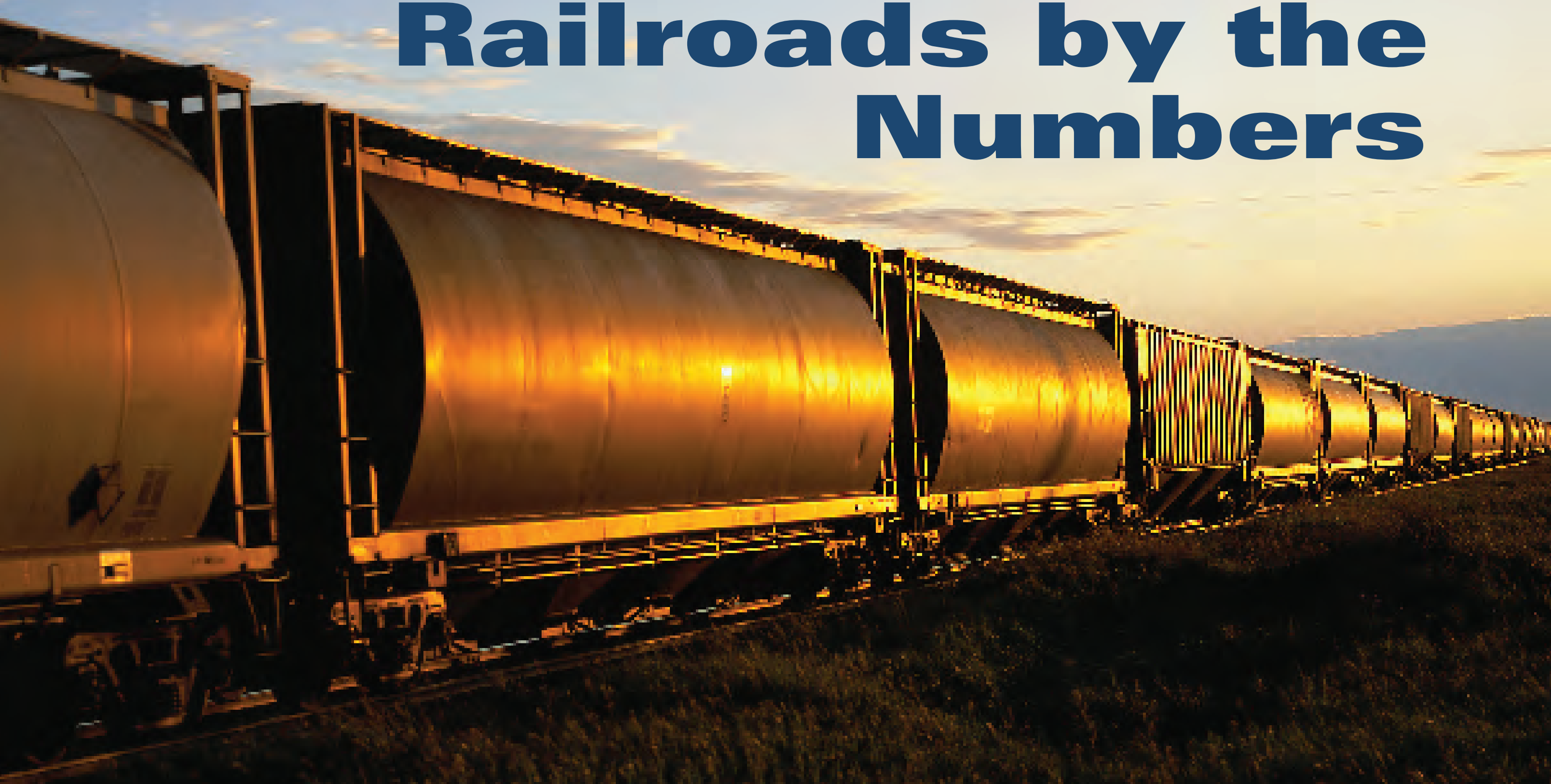
With the advent of the railroad, travelers were suddenly faced with the need to reset their timepieces at nearly every stop; train schedules in such a system were all but meaningless. In 1883, American and Canadian railroads simply decreed there would be five standard time zones running across the continent from east to west. In each time zone, on Sunday, November 18, people were required to stop and reset their clocks by anywhere from two to 30 minutes when the railroads said it was officially noon.

That day—which became remembered as "the day of two noons"—proceeded smoothly, but not everyone welcomed the change. In Indianapolis the *Sentinel* complained: "The planets must, in the future, make their circuits by such timetables as railroad magnates arrange … people must marry by railroad time, and die by railroad time."

But the New York *Herald* took a more philosophical approach: "The man who goes to church in New York today will hug himself with delight to find that the noon service has been curtailed to the extent of nearly four minutes …" Subsequently, a saloon owner in Iowa appeared before the state Supreme Court where he argued that he followed sun time, not "railroad time" and so had not violated closing time laws.

Nonetheless, the practicality of the system was hard to refute. The following year the International Meridian Council met and instituted the system used worldwide today, with Greenwich, England, serving as the prime meridian and 24 more-or-less equally spaced time zones circling the globe from there. In the United States, local time technically remained a local prerogative until the federal adoption of daylight savings in 1918. Internationally, the time zone system was not fully adopted in all major countries until 1929.

Railroads by the Numbers



$179 billion: Worldwide railroad transportation market in 2005 (estimated)

64 percent: Share of the 2005 railroad transportation market for Europe and North America

126 mph: Fastest recorded steam locomotive, the British *Mallard*, on July 3, 1939

361 mph: Fastest recorded speed of a Maglev train, the Japanese experimental MLX01.

149 mph: Fastest recorded diesel-powered train, the British *HST*, on November 1, 1987

129,066: Number of all types of train locomotives estimated by the World Bank to be in service (worldwide) at the start of the 21st century

419: Number of steam locomotives estimated by the World Bank to be in service (worldwide) at the start of the 21st century

1,181,903: Kilometers of railway track worldwide in 1999 (732,780 miles or about 29.5 times around the globe)

1.5 million: Number of people who work for the railroads in India

220 million: Weight (in pounds) of the world's heaviest train, which was 4.5 miles long and carried iron ore 171 miles in Western Australia on June 21, 2001, using eight locomotives

50 hours: Time it will take to get from Beijing to Lhasa, Tibet, aboard the soon-to-be-completed Quinghia-Tibet Railway, which will be outfitted with special UV-protected atmospheric cars to accommodate extreme altitudes; four-fifths of the railway is built at 4,000 meters (more than 13,000 feet) elevation