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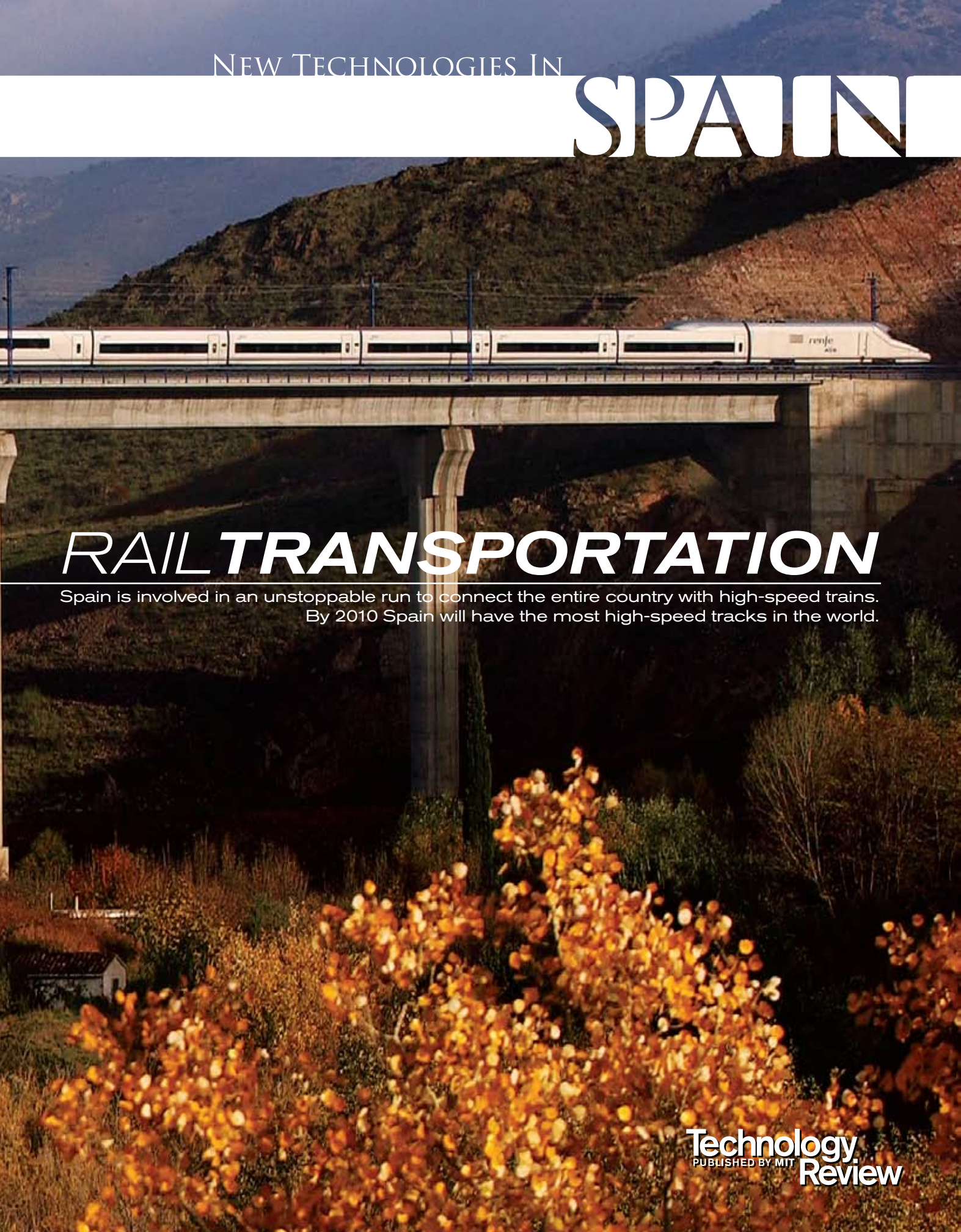

RAIL TRANSPORTATION

Spain is involved in an unstoppable run to connect the entire country with high-speed trains. By 2010 Spain will have the most high-speed tracks in the world.

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RAIL TRANSPORTATION IN SPAIN

The doors to the long-awaited high-speed rail line linking Madrid and Barcelona slid open in February 2008, connecting Spain's two main population centers and its two most significant hubs of business, technology, and research.

And this line, which represents the latest achievement in Spain's plans to connect the entire country with a web of high-speed trains, is far from the only news in Spanish rail. In the past few years, Spain has developed new metro systems, commuter rail lines, and suburban trains, some of which link to existing or developing high-speed lines. In addition, the Spanish companies that consult on the engineering of new lines, perform the construction and infrastructure development, build the trains, develop the signaling and information systems, and develop and build related parts have taken their expertise overseas as rail continues its explosive growth in the international market.

MADRID TO BARCELONA

Though Madrid–Barcelona might seem like the ideal route to begin a high-speed network, the Spanish government actually launched the system in Seville in 1992, when the city was to host the World Expo.

The new system completely rerouted an existing track that had swerved around mountains and avoided technically challenging terrain. Taking advantage of the latest construction techniques to tunnel through any existing impediments, the line also used the top trains and technology available at the time. It slashed travel time from about six hours to two hours and 20 minutes.

"This first experience caused something like high-speed fever," says Ignacio Barron, the Spanish representative to the International Union of Railways, who directs the organization's high-speed department. "Everybody wanted to build new lines and extend the networks."

Plans came up against a temporary roadblock when Spain, along with the rest of Europe, hit a financial downturn in the 1990s. But they picked up again in 1997. Since then, the Spanish rail authorities–RENFE (the rail operator) and ADIF (the company in charge of infrastructure and planning, which was originally part of RENFE)–have overseen the building and installation of more than 1,500 kilometers (nearly 1,000 miles) of high-speed lines. In 2003 the line linking Madrid to Zaragoza and Lleida, en route to Barcelona, began service. The line from Madrid to Seville branched out to nearby Toledo in 2005, and the first line opening up the northwest of the

country began service in December 2007. Soon thereafter, the line south finished up in the popular coastal destination of Málaga.

Madrid–Barcelona, however, is the current jewel of the system. Like the Madrid–Seville line, the new train to Barcelona features an entirely new route, new tracks, and new trains—these equipped with swiveling seats and full video and audio capability. And like the country's first high-speed line, this one dramatically slashes travel time. A trip that once took more than six hours now takes just over two and a half. The new trains offer a smooth, swift ride at about 185 miles per hour, or 300 kilometers per hour. When new signaling systems are installed (they're expected for fall 2008), train speeds will be able to reach 220 miles per hour, or 350 kilometers per hour, and travel time will shrink to about two hours.

By 2010 Spain will have the most high-speed tracks in the world, and plans call for 10,000 kilometers by 2020. This would place 90 percent of the population within 30 miles of a high-speed station.

Experts in the field cite two and a half hours as a time at which rail is competitive with air travel. The line to Barcelona, at close to 400 miles, now competes with one of the most trafficked air routes in the world: five million passengers are expected to use it in 2008 alone. A rail line from San Francisco to Los Angeles would be shorter, at 347 miles. And Boston is only 50 miles farther by road from Washington, DC, than Madrid is from Barcelona, meaning it would be theoretically possible–politics, land-use planning, and finances allowing–to build a train that could connect those U.S. cities in about three hours.

The Madrid–Barcelona line also represents the beginning of a new planned link to France. T.P. Ferro, a company created by a coalition of the Spanish and French construction companies ACS Dragados and Eiffage, has already broken ground on a new tunnel underneath the Pyrenees, the mountains that separate the two countries. The tunnel will eventually cut two hours from the trip between Barcelona and Toulouse, and travel time from Barcelona to Paris will be reduced to four and a half hours.

GROWTH OF RAIL

Current international trends support the development of train lines around the world. The cost of gas is spiking at the same time as rail technology has enabled ever-increasing speeds. The growing focus on limiting greenhouse gases adds to the interest in improving existing lines or developing new ones. According to RENFE estimates, a train traveler from Madrid to Barcelona generates 13 kilograms of carbon emissions, while the same trip by air generates 70 kilograms.

Today, there are about 625,000 miles of high-speed lines in the world, according to Barron. The International Union of Railways (know by its French initials, IUC) predicts three times that total by 2025, he says. According to these predictions, about a third of the world's high-speed lines will be in Spain.

"Before, trains were competing with cars; now today's high-speed trains are competing with planes," says Mario Oriol, export and marketing director of the Spanish railway-vehicle manufacturer Talgo. "That shows how fast the train technology has developed."

In Turkey, the government is building a high-speed track connecting Istanbul and Ankara; Spanish construction companies OHL and Guinovart are involved in building the line, and Spanish manufacturer Construcciones y Auxiliar de Ferrocarriles (CAF) will provide the trains. The company also recently won a bid to supply suburban trains to the Turkish city of Izmir. In Saudi Arabia, a high-speed line now in the planning stages will link Mecca and Medina. Two groups of Spanish companies–CAF/OHL and Talgo/Isolux Corsán—are finalists in the bid, and CAF recently won a bid to supply eight trains to a future line.

> By 2010 the country will have the most high speed tracks in the world, with plans to expand to 10,000 km by 2020.

Tracks are also under development in North African countries such as Algeria, Morocco, and Libya, an area of interest and bidding for many Spanish companies. SENER, an engineering company whose transportation branch can cover a project's full cycle, has recently expanded into Algeria and is working on a metro and tramway. "Algeria has a lot of money from oil and gas, and they're investing it in infrastructure," says Cristina Ginés, SENER's director of international development. CAF is providing trains for the new Algerian metro.

Talgo and CAF have also supplied trains for rail projects in the U.S., including the Washington, DC, Metro and the Cascades railway in the Pacific Northwest. Many companies plan to submit bids when a final decision is made on plans for a potential high-speed link between San Francisco and L.A.

While Spain surges ahead in rail construction, China may be a close second, according to Barron. "China's rail system is creating a completely new network on the continental scale," he says. The Spanish information technology company Telvent is already operating in Chinese metros, and another Spanish IT company, Indra, is one of the finalists in the bid for control systems on new planned high-speed lines.

GLOBAL SOLUTIONS

By continuing to innovate, Spanish companies are able to grow along with the rapidly increasing market. Talgo, for example, is providing trains for Bosnia and Herzegovina, in the former Yugo-

slavia, where the rebuilding of the rail system reflects the advent of peace and economic development.

The project originated in 2000. "We took a train over— the first train to run on the line again after the war in Croatia and Bosnia–Herzegovina," says Oriol. "And during the test run we were guarded, leaving one station in Bosnia by helicopters from the Spanish army, which had been involved in humanitarian activities there. That was the project's kickoff."

Having worked with the conditions in Spain–steep mountains, tracks that curve around various topographical impediments–Talgo was well prepared for the mountainous geography of the Balkans. The company had developed lightweight aluminum trains with articulated cars, so that a train can be indivisible instead of comprising different segments. Thanks to its system of wheels that are mounted in pairs but not joined by axles, the wheels move along the track independently, leading to a more comfortable ride. These elements save energy, lower costs, and make trains faster, safer, and more comfortable.

"Our lightweight technology and independent and guided wheel system were ideal for that area," says Oriol. "In Bosnia, they found these trains quite interesting, because they saw that without any investment in infrastructure, the trains still reduced journey times by 20 to 30 percent." Talgo is supplying 81 passenger coaches, which will form nine trains.

Oriol says this project has important implications in the region: "Bosnia–Herzegovina is actually going to reëstablish all railway connections that existed in Yugoslavia before the war, from Sarajevo to Zagreb in Croatia, to Slovenia, to Belgrade in Serbia." The trains will be delivered in 2010, after track rehabilitation is complete.

The company also supplied trains to oil-rich Kazakhstan, which recently moved its capital from the south to the north. The previous Soviet-era train could make the journey in 21 hours, but Talgo trains reduce the ride to 13 hours, so an overnight train can bring workers from the newly designated capital back to their families down south for the weekend.

The weather extremes in Kazakhstan–from 45 °C (113 °F) in the summer to –45 °C (-49 °F) in the winter–posed technical challenges for Talgo engineers. They created a floating elevated floor to avoid touching the frame, which is exposed to the elements. They used different components and different steel alloys. "Basically, it was a complete redesign," says Oriol. The trains were delivered in 2003 and have been running smoothly, sun or snow. The gauge-switching trains for which Talgo is best known could also be useful should Kazakhstan and China decide to link lines, since China uses a narrower rail gauge than Kazakhstan.

FUNDING THE GROWTH

When it comes to financing, one of the trends taking place around the world is the privatization of public projects. A company, instead of the government, will supply all the necessary development funds for a project such as a new highway. The company–or companies–will then be repaid through the tolls or fares that would traditionally go back to government coffers.

This approach is becoming especially popular in countries where cash for up-front investments is scarce. CAF, which has been working in Mexico for 14 years, won the 30-year concession for the new suburban train line from Mexico City out into the surrounding state. The company is responsible not only for supplying the trains but for overseeing the construction, signaling, and telecommunications–all the necessary aspects of developing a new train line. Companies involved in the project as subcontractors include construction company OHL for the civil works, Indra for ticketing, Thales for signaling and telecommunications, Inabensa for electrification, and Telvent for the control center.

CAF sees this as a strategic beginning. "We saw that there was a lack of funds for investment [in Mexico]," says Luis Giralt, CAF's international director for Latin America, "but certainly no lack of a need for this type of transport."

After two years of construction, the line began operation in the spring of 2008. "Before, passengers along this line took an hour an a half to get into Mexico City," says Giralt. "Now the commute takes only 25 to 27 minutes." CAF has managed to hold down prices to match those on the bus line.

"The response so far has been very positive," Giralt says. "People see that the trains are modern and air conditioned, and they get from home to work much faster and much more comfortably than before."

India, which is planning a multibillion-dollar upgrade and expansion of freight and passenger rail, is also investigating concessions as a means of financing, constructing, and supplying the rail lines. Isolux Corsán, a top Spanish construction company that also specializes in engineering, electrical wiring, and signaling, looks forward to the potential. "They're planning concessions in railway stations, for freight corridors," says international-business director Álvaro Rengifo. "We have local partners and are getting ready."

They company already has rail projects in development around the world. Rengifo says that experience with all aspects of rail development along Spain's high-speed corridors has helped Isolux Corsán grow internationally and win concessions abroad.

RAIL REVIVAL

Because high-speed rail allows for easy, zippy travel between urban powerhouses, it has carried economic benefits to smaller cities along the way.

When the AVE (the Spanish acronym for the country's high-speed system) brought Ciudad Real and Puertollano to within an hour of Madrid, both cities were strengthened economically. The newfound proximity solidified Ciudad Real as a university and regional business center, and the effect spilled over into nearby Puertollano.

Researchers study the best ways to improve the performance of high speed trains.

Along the Madrid–Seville line, the city of Córdoba, formerly a regional industrial center, took the arrival of rail into account to manage new development. City planners moved the rail lines underground and rebuilt the station, freeing swaths of green space, and designed a corridor of hotels, conference centers, and other facilities to attract visitors. The city profited both physically and economically.

Zaragoza, midway between Madrid and Barcelona, has already reaped the benefits of the high-speed line that reached the city in 2003, and it expects to gain even more by the time the line is complete. The city, already a regional hub, capitalized on the new station by expanding related businesses and services and by hosting 2008's International Exposition on Water and Sustainable Development. In the past, travelers rode for three to four hours to reach Zaragoza from Madrid or Barcelona; the AVE cut that time in half. The city has developed hotels and facilities to attract meetings and conferences. "Zaragoza can serve as the point between the two cities," says Jose Luis Abad of the group High Speed Zaragoza. "We've been able to take advantage of new line to modernize the city— transform it into a modern center, a perfect business meeting place." Zaragoza also houses Indra's high-speed control center, with its walls of vibrant lines and dots representing trains as they move around the country in real time.

Mikel Murga, managing director of the Spanish consulting firm Leber and a lecturer at MIT, has served as an advisor on rail issues around the world. One city where he consulted was Bilbao, which opened its metro system in 1995. "Because of the subway, the city has evolved and changed," he says. "Elected officials have been emboldened to act in ways that would never have been possible before the subway."

Murga explains that the city has been able to focus planning on pedestrian traffic instead of cars; one project calls for making the downtown region a pedestrian-only plaza. "These are the kinds of changes that can only be explained by the contribution of rail," he says. The economic benefits reach individuals, too. "Young people who are trying to pay a mortgage—if they need two cars because they live far out of the city, there's a tremendous impact on their budget," Murga says. "We've made estimates of an additional 2,000 euros (currently about $3,200) per person per year, depending on whether someone has to rely on a car or not."

TRAINS TO THE FUTURE

When Spanish rails were first placed, in the 1800s, they were significantly wider than the tracks in France and the rest of Europe, walling the country off from its neighbors. In the 1960s, however, RENFE decided to operate trains that could easily move to French lines. To meet this need, Talgo designed its signature variable-gauge trains, which can switch from one gauge width to another. The company has

PHOTO COURTESY OF CAF

Spanish companies utilize cutting-edge materials and technologies to achieve a faster, safer, and more comfortable ride.

PHOTO COURTESY OF TALGO

been operating such trains between Madrid and Paris since 1968.

For the new high-speed lines, the Spanish government decided to build the entire system on standard tracks to facilitate travel to neighboring European countries. Both Talgo and CAF came up with solutions for automatic systems that allow trains to switch between gauges without coming to a complete stop. In both systems, the change–which in the past took up to an hour–takes only about four seconds.

Meanwhile, both CAF and Talgo have developed different types of proprietary technology in what are called "tilting" trains. Tilting technology detects where and when the track curves, and it enables the train to lean into the center of the curve. Tilting allows even conventional trains to travel faster through these parts of the track.

By introducing aluminum bodies for trains in place of conventional steel, Talgo also cut the weight of the cars by about 30 percent, significantly reducing energy needs. This strategy has since been adopted by other high-speed manufacturers. Today, train companies are investigating the use of composites, which are already widespread in the aerospace industry. A CAF train under development has a composite floor, which reduces the weight of this component by a full 70 percent. Talgo, which also has projects involving composites, is now looking into hybrid and solar-powered cars as well.

CAF heads a research project partially funded by the Spanish Ministry of Industry, in consortium with six companies and nine research centers, that seeks to improve the interoperability, energy efficiency, speed, and comfort of high-speed trains. Called AVI-2015, the project is focusing on improving the trains' tilting properties, adapting their shape to make them more aerodynamic, and finding more efficient ways for trains to run on different voltages of electricity. CAF expects that these improvements will allow high-speed trains to run efficiently and comfortably on standard train tracks as well.

CAF is also working to improve its trains for tram and light rail, a significant part of the company's business. It's developing trams that have energy storage systems on board, eliminating the need for wires that run above the trains along the outdoor tracks. This is especially important in historic areas with monuments and cathedrals, says Javier Goikoetxea, CAF's research project coördinator: "Many citizens complain about power lines in these regions." The new systems will also save infrastructure costs for

local governments. The company has won recent tram contracts in Edinburgh, Scotland, and in Antalya, Turkey.

Spanish train companies' research and innovations extend to infrastructure development as well. For the Guadarrama tunnel north of Madrid—the country's longest, and the first of this length in the world to have no intermediate ventilation shaft—the company Zitron designed a completely new ventilation system. It uses a series of tubes, improved aerodynamic fans, and air curtains–a pneumatic closure system using jets of air–to push fresh air through the tunnel.

"We've developed a very sophisticated system, and people from all over the world have visited, as it's something quite new," says Zitron's Pedro Quiros. The company has won railway ventilation contracts in Australia, Africa, Europe, and the U.S.

The construction of tunnels for high-speed rail "is without doubt one of the most complicated aspects of rail infrastructure," said Manuel Arnáiz Ronda, the president of the Spanish Association of Tunnels and Subterranean Civil Works, at a recent meeting in Spain. But Spain, he said, is "one of the top in the field," thanks to the years of experience its construction companies have gained in boring through challenging geological structures and navigating around urban obstacles.

ACS Dragados, which is involved in the Guadarrama tunnel, capitalized on that experience to win the bid for the expansion of the New York City subway, in partnership with an American company. ACS Dragados is constructing east-side access tunnels, using two hard-rock boring machines it owns. These are the first tunnels to be built in the subway system in 25 years, and the first ever to be built with boring machines. The system draws on the same techniques the company used to bore under the Pyrenees.

TIMELY ARRIVAL

Passengers in the Spanish train system are guaranteed that they will arrive on time or their fare is refunded. That doesn't happen often; RENFE prides itself on a 98.5 percent punctuality rate. This performance owes much to advances in information systems and signaling.

At the AVE control center in Zaragoza, Indra—one of the top European information systems companies—uses a complicated network of track sensors, signaling technology, radio transmitters, and computer systems to control Spain's high-speed network. The DaVinci system, which was developed for ADIF and began operations in 2003, integrates information about the trains and the rail system and updates all that information in real time or within a few seconds.

High-speed rail demands precise information gathering and transmission. Not only does the control center collect data on exactly where each train is at any given moment, but it gathers other types of crucial information as well. For example, data from detectors that test the temperature of the brake boxes helps the system avoid overheating and the resulting brake failure. The system also collects information on electricity demand in every part of the line. Fiber-optic sensors detect even small fallen objects along rail paths and then sound an alarm.

Jose Miguel Rubio, DaVinci's rail information system manager, says new research focuses on automating even more features of the control system, sidestepping human decisions. "So if you have a conflict in real time, where two trains want to go onto the same track," says Rubio, "the automatic routing system starts to scan the track for the best route to solve the conflict." The company is also involved in building a super control center in Madrid, which will oversee all tracks in Spain, not just the high-speed ones.

Passengers in the Spanish train system are guaranteed that they will arrive on time or their fare is refunded.

Newer, more accurate signaling systems will allow trains to run even faster. Says Javier Rivilla, project manager at Indra, "As we begin to increase rail speed, I believe we will keep on innovating and advancing within this system, making everything even easier to coördinate and even more automatic." These developments will increase the productivity of the entire rail system, but they will also demand increasingly precise data and data transmission.

Signaling presents one of the greatest challenges both in making trains faster and in achieving interoperability across Europe. Trains traveling at high speeds need at least 8 kilometers to brake, and 12 kilometers to brake smoothly–something impossible with road signals such as traffic lights.

"These signaling installations have to be designed in such a way that if you have a problem in one site, the system has to know at each moment where the rest of the trains are and get the information to all the trains, allowing them time to slow down and prevent a collision," says David Sanz, account manager for sales and marketing at Dimetronic, a Spanish signaling company that has been involved in a variety of Spain's high-speed projects.

In the past, however, each country used its own signaling technology, so trains crossing borders needed to be equipped with a variety of systems to read the different signals. To deal with this problem, in the early 1990s the European Union called for a standardized system. Known as the European Rail Traffic Management System (ERTMS), it was developed to be open and available for use by companies around Europe; any company could develop a system that would meet the European standards. The Spanish government, working in conjunction with top Spanish companies, pioneered the use of this

system in all the country's high-speed rail lines.

In what's known as ERTMS Level 1, all the track information, such as the location of trains, is centralized in a computer. The information is relayed back to trains by equipment along the track. The accuracy of this system allows trains to reach speeds of 250 to 300 kilometers per hour. Level 1 was first installed in Spain in a pilot program in 2002 and has been used for all new high-speed lines built since.

ERTMS Level 2, which is in final testing, uses less rail-side equipment and provides greater accuracy, so that trains can run even faster and more of them can run on a given track. Level 3, which is still under development, will allow still higher speeds and train densities.

Increased precision in transportation technology has allowed trains to run faster and more frequently, agrees Arturo Corbi, international director of transportation at Telvent, which operates control systems for trains and subways. "Ten years ago, in one lane there were probably two or three trains, and now you can have ten," he says. "Now, with the increased ability to know exactly where the trains are at any given second, you are able to have effective and direct control over the train that in the past was not possible."

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Telvent's expertise in control systems and related technology won it the bid to design and provide the ticketing system for the first subway system in Tianjin, China, a city of about 13 million inhabitants. The local government wanted to try a different approach, "so we decided not to use tickets at all," says Corbi. "It was a challenge and a risk to base the system entirely on one technology, and the first such system in China."

Instead of individual tickets, the system relies on plastic cards, similar to Boston's Charlie Card or the DC subway's SmarTrip card. Both those systems, however, also offer the option of standard ticketing. In the system Telvent designed for Tianjin, passengers buying individual rides get tokens equipped with the same chip that's in the plastic card, creating a "contactless solution."

There are many benefits, according to Telvent. "You help make it comfortable and easy for the users, and you avoid maintenance costs for the operator [by having one system instead of two]," Corbi says. "Also, there's no paper, so it's more sustainable." The line opened in 2005 and has been running successfully for a year; the fare system will now be extended to two additional lines.

Telvent has applied what it learned from the Tianjin project in Latin America, in Monterey, Mexico, and in a train line in Venezuela. The company is also working on technology that makes the system more accessible, such as voice-recognition vending machines for the visually impaired.

Those involved in rail say it's an exciting time in the expanding sector. "There are a lot of technological improvements, a lot of work to be done, a lot of projects going on," says Indra's Jose Miguel Rubio. "Ten years ago, rail couldn't reach the current speed, and now it can easily compete for medium distance with planes. It's the ultimate transport solution."

Resources

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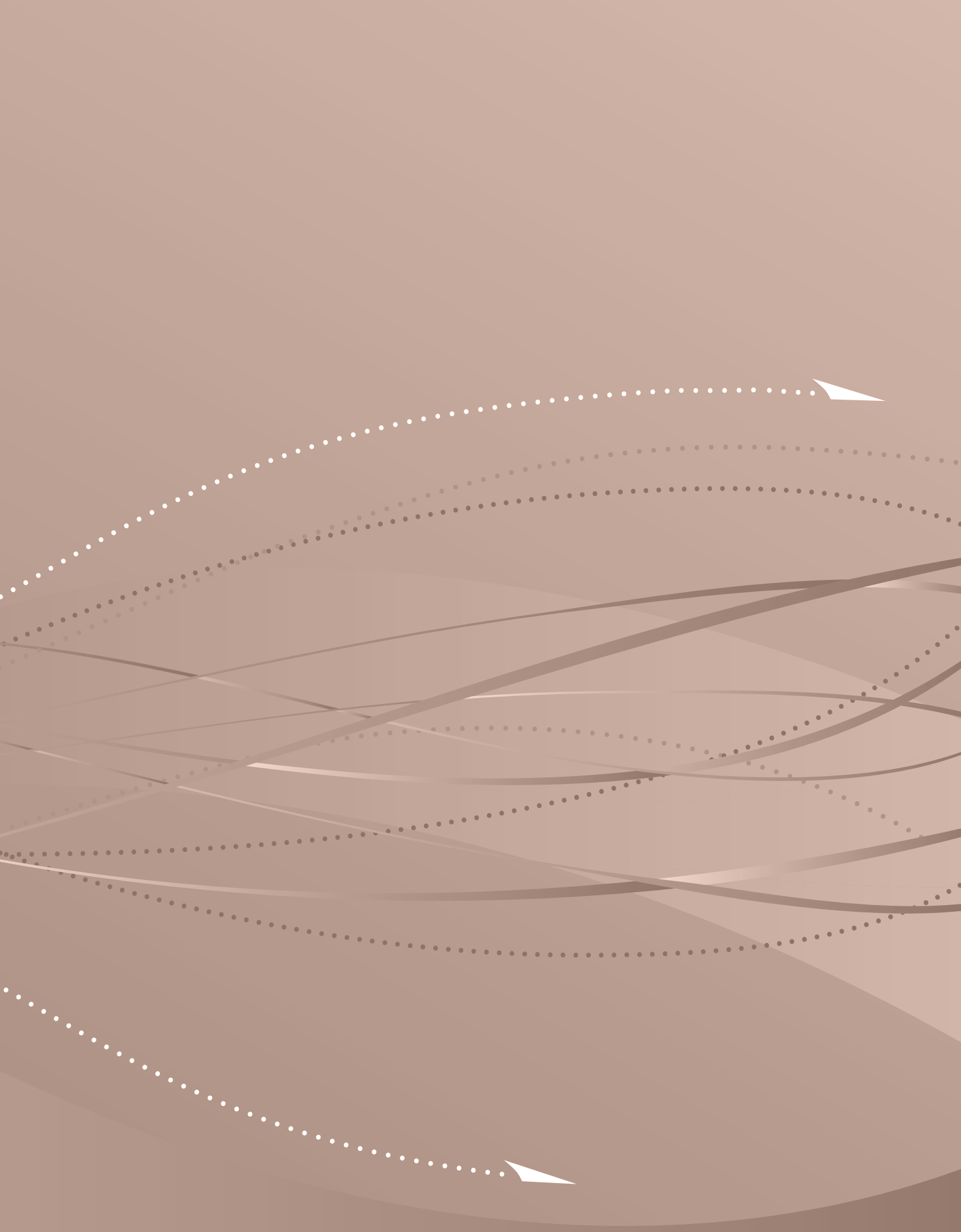

New Technologies in Spain Series

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As part of this initiative, Technology Review's custom-publishing division has produced the New Technologies in Spain Series, which appears as a special supplement in MIT's Technology Review magazine and a multimedia special section online. This powerful multi-part series showcases the technological development and excellence of Spanish companies in several important industries, such as wind energy, water desalination, high-speed rail, aerospace, industrial machinery, biotechnology, and solar energy.

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