

New Technologies in Spain



High-Speed Railways

To meet the world's growing demand for high-speed rail networks, Spanish companies are innovating numerous new products and services.

Innovation in Motion

Spain is now the world's eighth-largest economy and the fastest growing in the European Union. It represents more than 2.5% of the world's total GDP and a third of all new jobs created in the Eurozone last year. Spain is fast becoming a leader in innovation and generating advanced solutions in the industries of aerospace, renewable energies, water treatment, rail, biotechnology, industrial machinery and civil engineering. Spanish firms are innovators in the field of public-works finance and management, where six of the world's top ten companies are from Spain. Where innovation thrives, so will the successful global enterprises of the 21st century.

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High-Speed Railways in Spain

Spain is rapidly expanding its high-speed rail service, becoming one of most connected countries in the world. As the high-speed rail network grows, Spanish companies continue to innovate and provide new services and products at lower prices to meet the world's growing demand. This is the fourth in an eight-part series highlighting new technologies in Spain and is produced by Technology Review, Inc.'s custom-publishing division in partnership with the Trade Commission of Spain.

The sensation of riding on Spain's high-speed rail from Madrid to Seville is more than anything one of smoothness, without the bumps and jostles common on conventional rail. The journey passes so comfortably, in fact, that it's easy for a rider to forget the speeds at which the train is traveling—unless, of course, the rider happens to stand in the conductor's cabin. From the conductor's vantage point, scenery zips alongside as tunnels loom ahead, then the train quickly plunges into darkness before darting out once again into the light. The speed, the most important trait of high-speed rail, turns from simply a number on paper into something visceral.

Spain has embarked on an ambitious project to develop high-speed rail connections in every major city, spanning out in a web all around the country and connecting the urban dots along the coast. By 2020, the country plans to have 10,000 kilometers of high-speed rail completed, placing 90 percent of

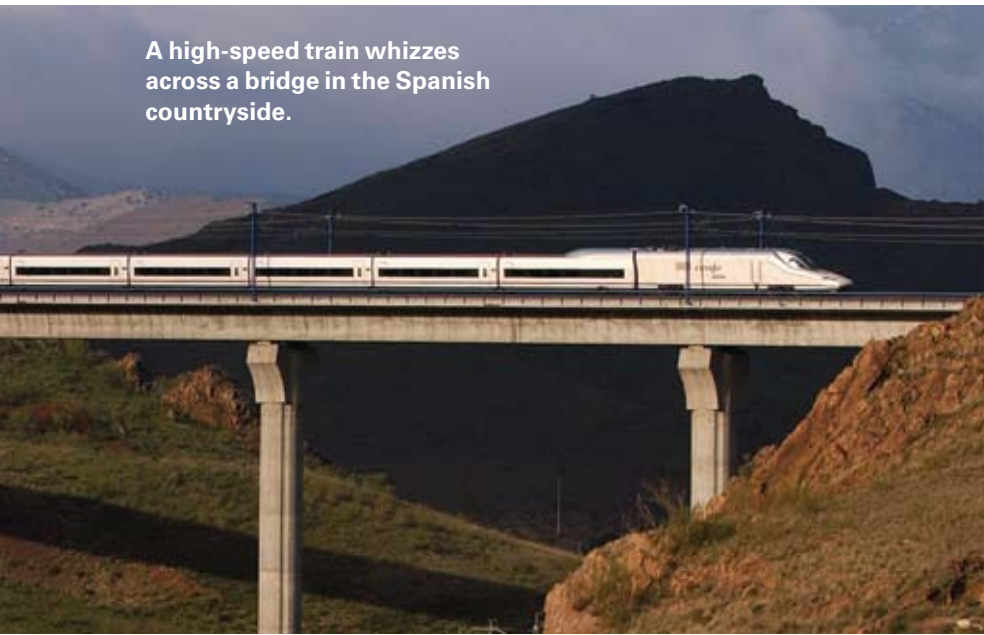
the population within only a few dozen kilometers of a high-speed rail line and shooting Spain to the world's top ranks in terms of total high-speed rail on the ground.

In the process, Spanish industry has taken advantage of the country's new focus on high-speed rail to develop new products to meet the demand of Spanish market, and to innovate and compete on the world market for parts and services.

What Is High-Speed Rail?

The history of rail is long and varied around the world, and definitions of "high speeds" have changed dramatically over the years. Railways had a monopoly on passenger travel throughout the late 1800s and early 1900s at speeds that were considered rapid at the time—about 100 kilometers per hour.

A high-speed train whizzes across a bridge in the Spanish countryside.



After World War II, the United States came to rely on improvements in cars, highways, and air travel, while Europe and Japan focused on rebuilding and improving the railway system. Higher-speed trains were originally imagined in order to win back large numbers of passengers who had been diverted to road and air traffic (reasons similar to those motivating Spain today).

Today, “high speed” trains are generally understood to be those that travel at and above 200 kilometers per hour, or 124 miles per hour. That speed was first reached by a Japanese train, which was officially launched in 1964. France’s TGV followed in 1981. Actually, 200 kilometers per hour is now considered relatively slow in the high-speed world: most high-speed trains today travel at 250 to 300 kilometers per hour (150 to 185 miles per hour). Trains are in development that run at 350 kilometers per hour, and on test tracks, trains have reached more than 500 kilometers per hour.

The term “high-speed rail” does not refer to a particular type of train but, rather, simply to the speeds it can attain. Today most high-speed trains are electric, though diesel trains, incorporating newer technology, have been able to reach similar speeds. For instance, the Spanish company Talgo has a diesel

train that reached 250 kilometers per hour in testing, though its trains purchased for systems around the world remain electric.

History

The history of high-speed rail in Spain began two decades ago, in 1986, when the government decided to further the country’s investment in rail. At the time, involved officials in Ministries of Economy and Transportation and the office of the President debated whether to develop improved and additional conventional rail lines or take the plunge with high-speed. Spain has a particularly high density of air travel, with each regional capital having its own airport, and the government determined that high-speed rail presented the best economic and environmental alternative to attract people away from planes and cars.

As to where that first line would run, the government chose the Madrid-Seville route. Though it might seem less logical than linking the two major economic centers, Madrid and Barcelona, a number of factors made this track a clear first choice. Before 1986, traveling to Seville from Madrid meant a long, indirect route over a single-track rail. “This was technically the most important bottleneck in the network,” says Joaquín Jiménez, director of interna-

tional relations for ADIF (the Spanish acronym for the Railway Infrastructure Administrator). Says Jiménez, “This line was the one where, with the least investment, we could dramatically cut the distance for the largest number of passengers by building a new line entirely, not running parallel to existing train lines.” In addition, the World Expo planned for Seville in 1992 gave the government a time and goal to work toward.

There were practical economic reasons to choose Seville for the first destination. That same year, 1986, Spain entered the European Union. With the entrance, the Spanish government had access to EU funds for infrastructure development, and the government decided to invest in the development of the relatively impoverished region of Andalusia.

The construction of the line was hampered by the need to cross the Sierra Morena mountains. “Spain is the second most mountainous country in Europe, after Switzerland,” says Juan Matías Archilla, director of international relations for Renfe, the Spanish rail operator. Today, improvements in tunnel engineering assist in the development of shorter rail lines; Spain is currently building one of the longest rail tunnels in the world north of Madrid, crossing the Sierra de Guadarrama along the new high-speed route between Madrid and Valladolid and serving the entire northwest of Spain.

It took only six years for the 471-kilometer line to be completed, an unusually short time for a line of this distance. It cost about a third less than similar lines—in part because of the dogged commitment of the local and national government to achieving the goal in time for the World Expo.

After the trains finally reached optimal speed, it took just two hours and twenty minutes to reach Seville. Before, any rail traveler would spend nearly triple that, about six hours. Riders soon arrived in droves, and the line proved to be a crucial link in the economic development of the region.

After the success of the Madrid-

Seville line, the economic crisis of 1993 hit Spain, along with much of the rest of the world. It wasn't until 1997 that the country found itself on strong enough economic legs to return to the theme of high-speed rail. The view automatically turned to developing the route between Madrid and Barcelona, with the idea of cutting travel time from six and a half hours down to about two and a half.

In 2003, the next line of Spanish high-speed rail (known by the Spanish acronym AVE) opened in Spain: from Madrid northeast to Lleida, which is the beginning of the lines both to Barcelona (to open in 2007) and to the French border. The trip time was reduced by half. By early 2005, a shorter-distance high-speed line opened up southward from Madrid to the nearby town of Toledo. By the end of 2006, the southern lines stopped along the coast; they will reach the popular tourist destina-

tion of Málaga by 2007. Construction is already in advanced stages for lines reaching the Mediterranean coast and the French border.

Why Rail?

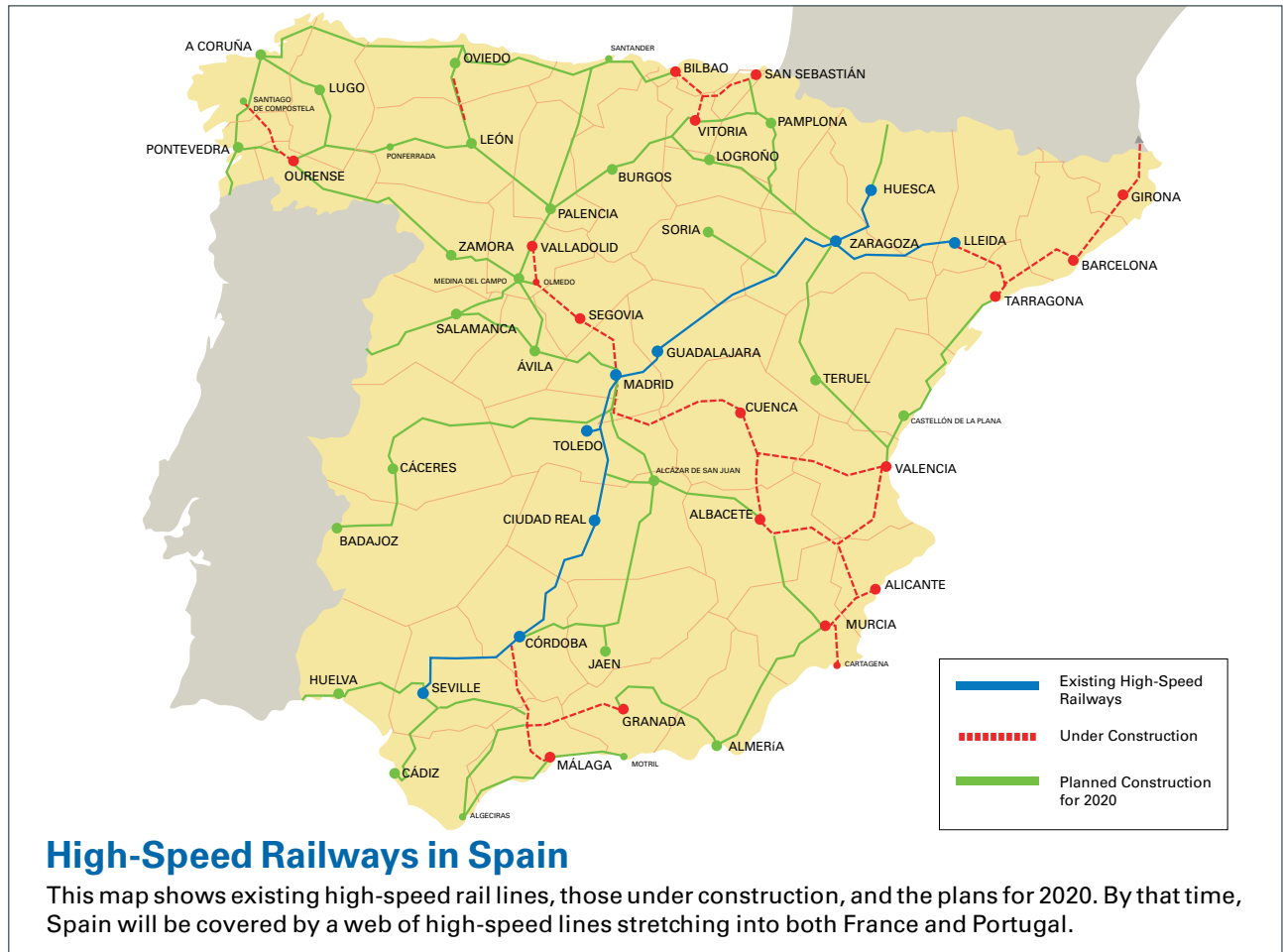
As Spain strengthened its economy in the 1980s following its emergence from economic isolation, the decision about how best to invest in infrastructure development became paramount. Rail offered a wide variety of benefits. Development of rail, it was determined, provided the best means for increasing economic development in the outlying areas of the country by providing speedy and straightforward travel between cities, while addressing environmental concerns. "Until 1986, rail had been languishing," says Jorge del Fresno, vice president of Ineco-Tifsa, a rail consulting and engineering company. "It had been doing worse and worse because people weren't satisfied

with the rail service, and they turned increasingly to roads and planes."

The decision to invest in high-speed rail also came about in part because of a need to reduce greenhouse gases under Spain's participation in the Kyoto Protocol. Rail, which runs on electricity (and electricity in Spain is partly generated by renewable sources such as wind), is significantly cleaner than either planes or cars. The data for the Madrid-Seville line support the investment in high-speed rail: before the advent of the new line, 11 percent of passengers traveled to Seville by plane and 60 percent by car. After the AVE began service, only 4 percent traveled by plane, 34 percent by car, and more than half on the train.

"With rail and the use of significantly cleaner electricity," says Jiménez of ADIF, "our dependence on petroleum is greatly reduced."

According to Spanish government studies, consumers can be convinced to



switch to rail if the journey is as short as two and a half hours. Any minor reduction in time past two and a half hours does not significantly increase passenger demand along the line. “What we’ve found is not that the passengers need to arrive even more quickly,” says Jiménez, “but that they want access to the city centers in a timely fashion. Our stations have an advantage over flying due to their placement.”

The government has also studied public response to high-speed rail, and in general the response is highly favorable. In addition to the comfort and ease of travel, the line from Madrid to Seville offers the only money-back policy in the world that refunds the entire fare if there’s even a five-minute delay. The policy was implemented in 1994, two years after the Madrid-Seville line opened, and less than 0.25 percent of all trips since then have resulted in a return of ticket fares. (Though that assurance has not yet been implemented in all the newer lines, representatives say the goal is to have every high-speed rail line in Spain carry the on-time guarantee.)

In addition, the movement of passengers to high-speed has freed up conventional rail. Rail operators are taking advantage of this by increasing the commercial traffic on those lines.

After 2003, the government investments in rail, both high-speed and conventional, surpassed those dedicated to roads; they recently reached more than \$6 billion a year, approximately 0.6 percent of the Spanish GDP.

Trains

The rapid growth of high-speed rail in Spain has encouraged Spanish companies not only to create products that meet the demands of the Spanish market but to innovate in ways that allow these companies to compete on an international market as well.

In the early stages of the AVE in Spain, without strong home-grown high-speed rail technology available, French and then later German technology provided the mechanisms to reach

the necessary speeds. But the clear and growing market for high-speeds trains within the country provided the motivating factor for two veteran Spanish rail companies, Talgo and CAF, to develop those trains.

Talgo began as a rail company in 1942, when a Spanish engineer tested a new system for axles to avoid wear and tear on train wheels. In the following decades, Talgo provided trains for a variety of specific Spanish needs. In the late 1970s and early 1980s, Talgo engineers developed trains that reached then high speeds of 200 kilometers per hour. Talgo began providing high-quality, inexpensive high-speed trains in the early 1990s.

“In 1988 we came to the conclusion that we had to prepare ourselves for the growth of high-speed rail in Spain and in general in Europe,” said José Luis López Gómez, technology director for Talgo. So the company tested a new train on a testing bench in Germany and reached the record-breaking speed of 500 kilometers per hour, though this speed is not yet feasible in the real world because of physical and signaling constraints.

CAF was founded in 1917, providing parts and trams for Spanish lines, including the first metro in Madrid. The company formed an R&D department in 1969. “That to me is the most important date in the company,” says a spokesperson for CAF, “because that’s when we began to develop our own products.”

A Spanish disadvantage—mountainous terrain and frequently curving tracks—led to one Spanish innovation. Because of centrifugal force, as trains travel around curves, the speed pushes the train—and therefore the cars and the passengers within—to the outside of the curve, something that is known to cause passengers a fair amount of discomfort. This effect could also force trains off the rails. To avoid both results, trains often slow down at curves.

Both CAF and Talgo have developed proprietary technology in something

called “tilting” trains. Tilting technology detects where and when the track curves, and the train then realigns the suspension through a variety of systems and equipment so the train actually tilts into the center of the curve. This allows even conventional trains from both companies to travel at higher speeds through the curves.

Another particularly Spanish disadvantage has also paved the way for innovation. In the mid to late 1800s, when Spain was first developing its rail network, the country made a deliberate decision to use a gauge, or rail width, different from most of the rest of Europe. The Spanish gauge is 1668 millimeters wide, while the European norm is 1435 millimeters—a difference of more than 200 millimeters. Some experts say this different standard may have been adopted because of concerns over the possibility of invasions from neighboring countries; others say that at the time people believed a wider rail would work better with steam engines. Though the exact reason remains unknown, Spain was left with a major challenge in the development of cross-border travel and trade. Until recently, any train that wanted to cross from Spain to France had to stop, the wheels had to be totally reorganized, and the front car and engine had to be changed.

Talgo developed an automatic gauge-switching system that works in the following way. The train slows down to about 15 kilometers per hour when it reaches the switching station, which contains the original track and the new gauge alongside. At the station, there are lateral guides alongside the track. When the train encounters these guides, its weight transfers, freeing up the wheels and unlocking the bolts that hold the wheel system in place. The wheels automatically move to the newer gauge, and the locks set once again, transferring the weight back to the wheels and off the guides.

CAF trains also operate with a proprietary system developed along the same principles. The guides take the



weight of the train and unlock the wheels. As the train slides along the guides, loosening the axles within the system, the wheels readjust to the new gauge and are locked into place; then the train once again picks up speed.

In both systems, a gauge change—which in the past took up to an hour—takes only about four seconds. Talgo has been operating gauge-switching trains between Barcelona and Geneva since 1968 and between Madrid and Paris since 1980.

Today, the issue of changing gauges along a rail line is about more than frontiers. Spain made the decision to have all new rail lines, the high-speed lines, built at the European gauge width to facilitate movement between countries. Within Spain today, high-speed lines at European widths meet conventional lines at Spanish widths. CAF is operating trains along the Madrid-Barcelona line that change gauges without stopping.

Not only does this new technology allow Spain to easily move people and goods beyond Spanish borders, but it is opening up a new market to CAF and Talgo beyond the borders as well. Though most countries in Europe

built trains to the European gauge standard, some countries in the former Soviet Union have a gauge wider than the norm. Talgo tested this system at the borders between Sweden, Finland, and Russia. China and Japan have also expressed interest in the mechanism.

CAF and Talgo are both supplying trains to the Spanish high-speed rail market, and CAF has recently sold the first high-speed rails out of Spain for the new line between Istanbul and Ankara in Turkey.

Control Headquarters

In Zaragoza, midway on the journey from Madrid to Barcelona, one room's walls are lined with large panels that glow red, green, and blue against a black background. Marks representing trains blip as they move along luminescent tracks, their position constantly updated as they speed along real-world tracks many miles away. "We have a geographical view of the entire system, all the trains, as if we were seeing the whole system operating in real time," says Javier Rivilla, project manager at Indra.

This is the control center for the entire AVE system, a complicated net-

work of track sensors, signaling technology, radio transmitters, and computer systems that integrates every possible bit of information about the trains and the rail system and updates all that information either in real time or within a few seconds. Its developers like to boast that this system is among the most advanced in the world. "We're in charge here of making sure that everything functions perfectly," says Rivilla.

The company that synthesizes all the information is Indra, one of the top Spanish information systems companies and a top provider of defense contracts in that field. Internationally, Indra is also particularly well known for its air traffic control systems. "Of every five flights in the world, three are controlled by Indra," says Rivilla.

Indra engineers developed the new system starting in 2001 as a partnership with ADIF, while ADIF, searching for a more advanced method of traffic control and information flow, took advantage of the Spanish company's history of innovation in the development of information systems. The new system, called DaVinci, began operations in 2003. With more than four mil-



Information about high-speed rail lines is collected and monitored at the control headquarters in Zaragoza.

million lines of code, the system integrates all relevant information into a unified platform and automates all tasks related to the technical structure of the system, so the operator can focus on traffic flow.

High-speed rail, like air traffic, demands high-precision information gathering and transmission. Not only does the control center collect data on exactly where each train is at any given moment, but other types of information prove crucial to the functioning of the entire system, such as data from detectors that test the temperatures of the brake boxes so as to avoid overheating and thus a brake failure. The system also collects information on the

electricity demand in any part of the line. In addition, fiber-optic sensor systems detect even small fallen objects along rail paths and then sound an alarm to avoid harm.

Of course, throughout the years of high-speed rail around the world, any control system has needed to be able to identify fallen objects, to detect the position of the trains, to determine whether the trains are functioning as they should. In the past, however, each piece of information was determined, received, and transmitted by a separate system. For instance, if a train had to change rails because of a problem along a track, the operator had to contact all other operators in charge of related sys-

tems, such as the operator of that particular station. “What ADIF wanted was for someone in charge at the moment to be able to make a few clicks on a keyboard, change the path of the train, and everyone would immediately be notified, with all relevant changes in the system automatically updated,” says Rivilla.

All those systems have been totally integrated, which operators say is the particular strength of the Indra system. There are also redundant systems built in, in case one fails. Indra has taken advantage of technological advances in sensors and has developed proprietary information systems, coordinating the entire system on the Internet to provide maximum ease of use.

For the future, newer, more accurate signaling systems will allow higher train speeds along high-speed rail tracks. This will increase the productivity of the entire rail system, but it will also demand increasingly precise data and transmission of that data. Says Rivilla, “As we begin to increase rail speed, I believe we will keep on innovating and advancing within this system, making everything even easier to coordinate and even more automatic.”

Signaling

Signaling presents one of the greatest challenges both to the speeds trains can reach and to the interoperability of high-speed rail across the entire European network. Trains traveling at such high speeds demand at least 8 kilometers to brake, and 12 kilometers to brake comfortably and not alarm passengers—something impossible with, for example, 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 García, account manager for sales and marketing at Dimetric, a Spanish signaling company.

Each country, though, has devel-

oped its own technology, its own signaling systems. This has presented a challenge to the interoperability of the European high-speed rail network. Trains crossing borders needed to be equipped with a variety of technologies to read the different types of signals. To deal with this, in the early 1990s the European Union demanded a standardized system called ERTMS. It works by standardizing both the information and the means of transmission that trains automatically send and receive to and from signaling control systems, so as to obviate the need to change systems upon changing countries.

This new signaling system was developed to be open and available for the use and integration of any number of companies around Europe; any company could develop a system that would meet the specific European standards.

“It’s as if in 1990 there were no cars,” says Sanz. “So the government comes and says that we have to have a transportation system for everyone that works in all countries, and then goes and tells the industry to make cars. So let’s say each company, Volvo or Fiat or any of the others, each has its own

car, but each one is capable of traveling on all the roads.”

From the beginning, the Spanish government, working in conjunction with top Spanish companies, decided to be a pioneer in the establishment of this system, utilizing it for the construction of all the high-speed rail lines in the country.

So far, there are three levels of ERTMS; two are available and one is under development. In the first, a system of devices collects all the track information, such as location of trains, and centralizes it in a computer. The information is relayed back to trains by pieces of equipment along the track, which are called balises.

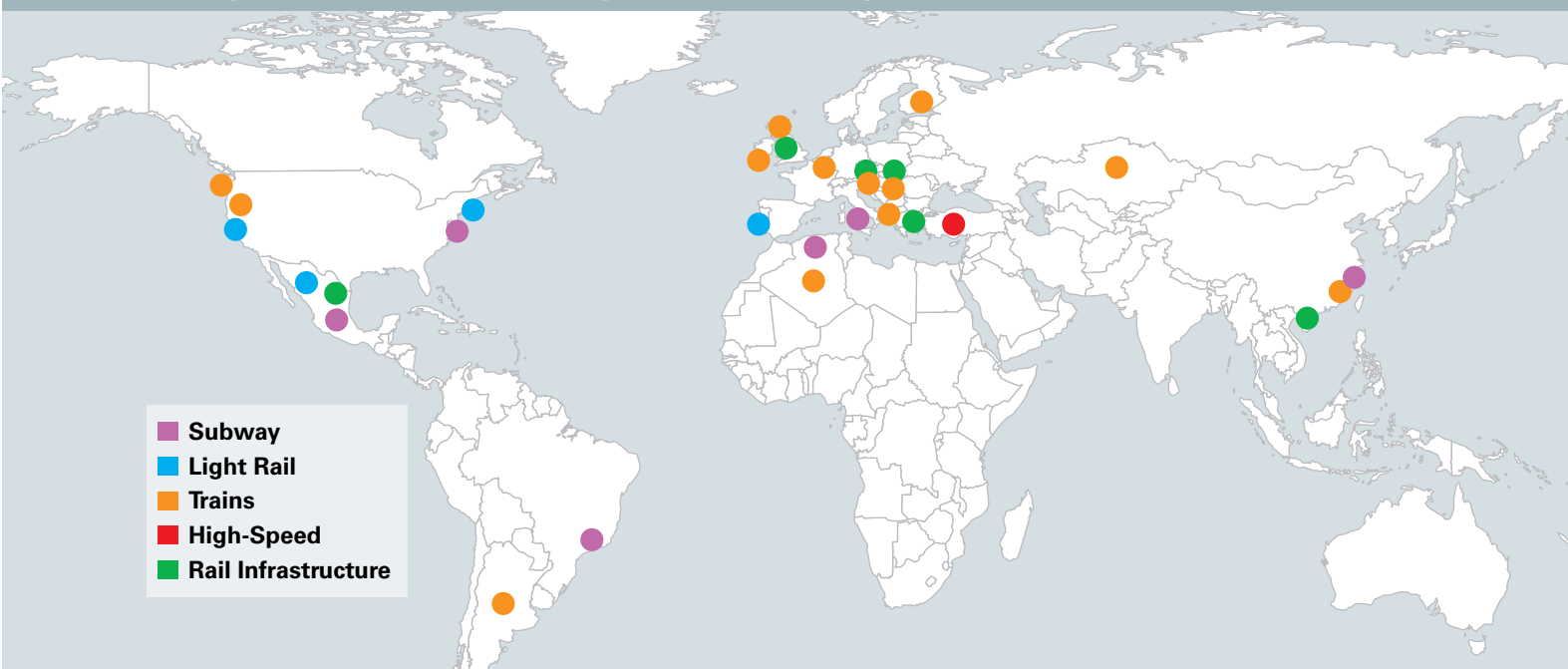
Every element of this system has been specified and standardized. The accuracy of this system allows trains to reach speeds of 250 to 300 kilometers per hour. Level 1 of ERTMS was installed in Spain for first use in a pilot program in 2002 and is being used for all new high-speed lines built since.

ERTMS Level 2 uses less rail-side equipment and provides a higher level of accuracy, thus both allowing trains to run at increased speeds and allowing an increased density of trains running

on a given track. Instead of using balises—discrete information delivery—Level 2 sends information continuously through a standardized radio system called GSM-R, using electronic safety equipment called radio block centers (RBCs). ERTMS 2 is in the final testing phase and will be commissioned by Dimetronic by the end of 2006 for the high-speed line between Madrid and Málaga in the south. Level 3 is under development and will allow even higher speeds and train densities on the tracks.

Dimetronic has taken the lead in Spain in developing a system to meet these needs. The system contains two main parts. One consists of the hardware: the balises and the electronic units that process the information that the balises relate to the trains, and the RBCs. The other is the system of software, programming each element and all the messages that will be transmitted. This, however, is similar to what all other signaling companies are designing around Europe. “As ERTMS is standardized, there are more subtle ways for companies to distinguish themselves from one another,” says Sanz, “such as the reliability of the

Sample of International Spanish Rail Projects



system and its general performance.” Dimetronic has designed peripheral equipment and subsystems of the signaling system that make it competitive on the international market.

The design of a testing system has made the biggest difference in the Dimetronic technology. This complex computer system allows engineers to input all the relevant data and ensure that all testing can take place in a laboratory, avoiding long real-time trials and resulting delays in the system’s use. Says Sanz, “This system is something that no other company has. It’s not the core of ERTMS, but it’s a related product that adds value and allows the client to put the product into service that much more quickly.”

Building the Rails

Pig iron and steel shine incandescent orange at the Aceralia mills in northern Spain, owned by the Arcelor-Mittal group. The furnaces and mills at the sprawling site have churned out more than 400,000 tons of high-speed rail for use in countries including Spain, Portugal, France, and Germany, making this site one of the largest rail producers in the world.

The points at which individual rails are soldered together create a weakness in the rail. Railways for high-speed trains must be longer than 270 meters after electric welding in order to lessen this effect. Arcelor Rail developed the facilities for high-speed rail in 1990—a kilometer-and-a-half-length building filled with the clangs and heat of metal production. In a building this size, Arcelor is able to provide 90-meter-long rails, significantly longer than rails needed for conventional tracks. “With a longer rail, the security of the rail is higher because of the avoided soldering points,” says Fernando Sáinz-Varona, rail marketing and controller manager. “And the cost is lower, as welding also adds to the cost of the rail.”

High-speed rail demands that metal meet very exacting standards. The quality and homogeneity of the material must meet a strict standard and be developed with specific

temperature and chemical requirements. This avoids, for example, an imperfection that could lead to a stress fracture in the rail.

To maintain these standards, Arcelor has created an ultrasonic testing system so particular to this type of material, and so proprietary, that no photos of the equipment are allowed. A physical sensor tests external surfaces for even the most minor imperfections, and ultrasound waves measure the internal quality of the material. “For high-speed rail, everything has to be perfect, both inside and outside,” says Sáinz-Varona.

In addition, Spanish construction companies, with years of experience designing and building the necessary infrastructure for rail, are now taking their expertise overseas in countries such as the U.K., Mexico, and China.

Speeding Ahead

As the Spanish government continues to rapidly implement plans to upgrade existing rail lines and build new high-speed rail lines around the country, more and more Spaniards flock to take advantage of the increased flexibility and mobility. Half of the \$252 billion budget for the 2005–2020 Transportation Infrastructure Plan is dedicated to rail. According to government estimates (based on the economic value of added jobs, increased mobility, saved time, and decreased pollution and carbon dioxide emissions), rail in Spain contributed to the Spanish government more than three times the amount it received in subsidies.

“We’re extremely proud of where we are,” says Jiménez of ADIF. “We started with a rail system that was not very competitive, had deteriorated a great deal, was very old—and was even shutting down. Within a short period of time, all that changed. And we’ve also reached a very competitive technological level, with companies providing equipment, components, civil works, and construction that compete on the international market. All of this makes us very proud of the Spanish model.”

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New Technologies in Spain Series

Spain is a technologically and industrially advanced country committed to innovation, research and development, both through its government and through its private sector. The country is determined to deepen and intensify its productive specialization in industries that depend on technology and innovation. The Ministry of Industry, Tourism and Commerce has launched an ambitious plan combining its available human and financial resources and setting out specific lines of action with the goal of strengthening the international outlook of the most technologically advanced companies in Spain.

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

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