TECHNOLOGY TRENDS IN HIGH-SPEED RAIL

Issue Date: June 2011

Abstract—*Current economic drivers and increasing environmental awareness are raising the demand for significant expansions of high-speed passenger rail networks globally to improve the connections to population centers within countries and to support a closer integration of economies internationally. This paper describes the emerging technological trends that promise to promote engineering advances in future high-speed rail (HSR) lines. These advances will enable faster, safer, more comfortable and reliable passage to a wider range of destinations while limiting environmental impact and minimizing capital and operating costs.*

Keywords—*high-speed rail (HSR), rail technology, requirements management, systems engineering*

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INTRODUCTION

Over the course of more than a century, steady improvements in the mass transportation of people and freight have made major advances in global industrialization feasible. Today, as a result of the rapid expansion of transportation modes (e.g., shipping, aviation) and infrastructure (e.g., highways, railways), people and goods are efficiently transported between cities and across international borders.

Especially significant over the past 40 years has been the considerable increase in the number of dedicated high-speed passenger rail lines that offer safe, fast, comfortable, and reliable journeys over long distances in many regions of the world. In particular, Western Europe, South Asia, the Middle East, and the Far East are seeing large investments in rail transport infrastructure to meet increasing demand. Concurrently, railway technology in general and higher speed applications in particular are emerging at an ever faster rate to support the economic drivers and to meet higher safety, reliability, performance, and comfort requirements while achieving more stringent environmental sustainability targets.

This paper discusses key economic factors promoting demand for high-speed rail (HSR). The paper specifically focuses on the technologies that are emerging to give this form of rail transportation a further market edge in terms of economic and business benefits over the next 20 years. The paper also provides an overview of how major rail networks worldwide are likely to expand during the same time frame to meet growing customer expectations.

BACKGROUND

Railways in Mass Transportation

Since their advent 200 years ago, railways have emerged all over the world as a means to transport people and freight using dedicated infrastructure and rolling stock. The capital investment and ongoing operating costs associated with railway infrastructure are offset by the much greater social, economic, and environmental benefits that accrue over several decades of operational service.

Early railway developments took place largely in the UK and the US. Since then, railways have taken many different forms to meet specific operational requirements. Today's railways run the gamut from metropolitan and suburban light rail systems to interurban heavy-rail commuter systems, dedicated long-distance freight lines, and high-speed passenger rail lines that connect the major cities of the predominantly developed economies.

High-Speed Rail Defined

Several definitions of modern HSR are in common use. In particular, European Community (EC) Directive 95/58 defines conventional HSR (i.e., trains with steel wheels rolling over fixed steel rails) as consisting of rolling stock and infrastructure that accommodate operation at speeds of over 250 km/h (155 mph) on new tracks or 200 km/h (125 mph) on existing upgraded tracks. The Chinese, Japanese, and Korean railway authorities concur with this definition.

The French Train à Grande Vitesse (TGV) has set record speeds and provided growing quality of service over the past two decades.

ABBREVIATIONS, ACRONYMS, AND TERMS

CBTC	communications-based train control
EC	European Community
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
HSR	high-speed rail
km/h	kilometers per hour
LED	light-emitting diode
mph	miles per hour
MTBF	mean time between failures
RTO	remote train operation
SIL	safety integrity level
TGV	Train à Grande Vitesse
TSI	Technical Specification for Interoperability
UPS	uninterruptible power supply
VE	value engineering
WLC	whole-life cost

Emergence and Growth of High-Speed Rail

Japan introduced the world's first high-volume, high-speed trains as early as the 1960s. Up to 12 cars in length, they traveled at 210 km/h (130 mph). Outside of Japan, the French Train à Grande Vitesse (TGV) has set record speeds and provided growing quality of service over the past two decades. More recently, China has successfully embarked on the engineering of its major integrated HSR network. China's ambitious program involves developing its overall rail network from the current 86,000 km (53,400 mi) to 120,000 km (74,600 mi). When this expansion is completed, trains will be able to offer scheduled passenger services at 350 km/h (218 mph) between more than 70 principal Chinese cities. The engineering of major high-speed lines is also underway in many other parts of the world, particularly in Western Europe, South Asia, and the Far East, with the Middle East following very soon. The US, South America, and South Africa are also considering introducing new high-speed lines.

Figure 1 provides an overview of key historical technological milestones in the development of HSR. An overview of the anticipated future expansion of HSR networks throughout the world is provided later in this paper.

ECONOMIC DRIVERS AND BUSINESS REQUIREMENTS

Three primary economic drivers are promoting an increasingly wider consensus to invest in HSR lines. These drivers can be broadly categorized as:

- Political/economic
- Environmental
- Social/demographic

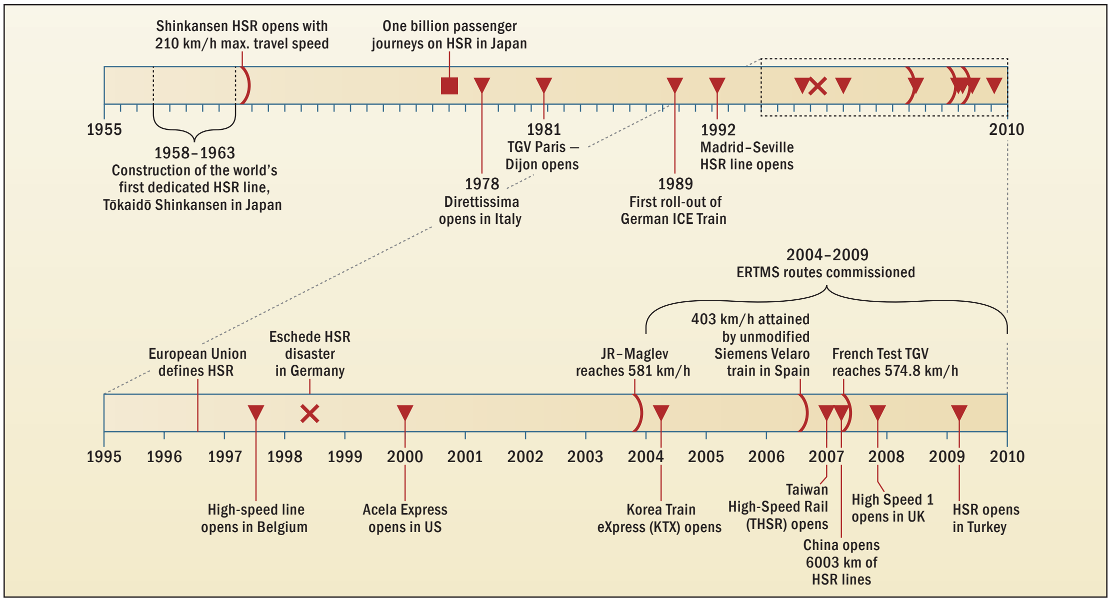
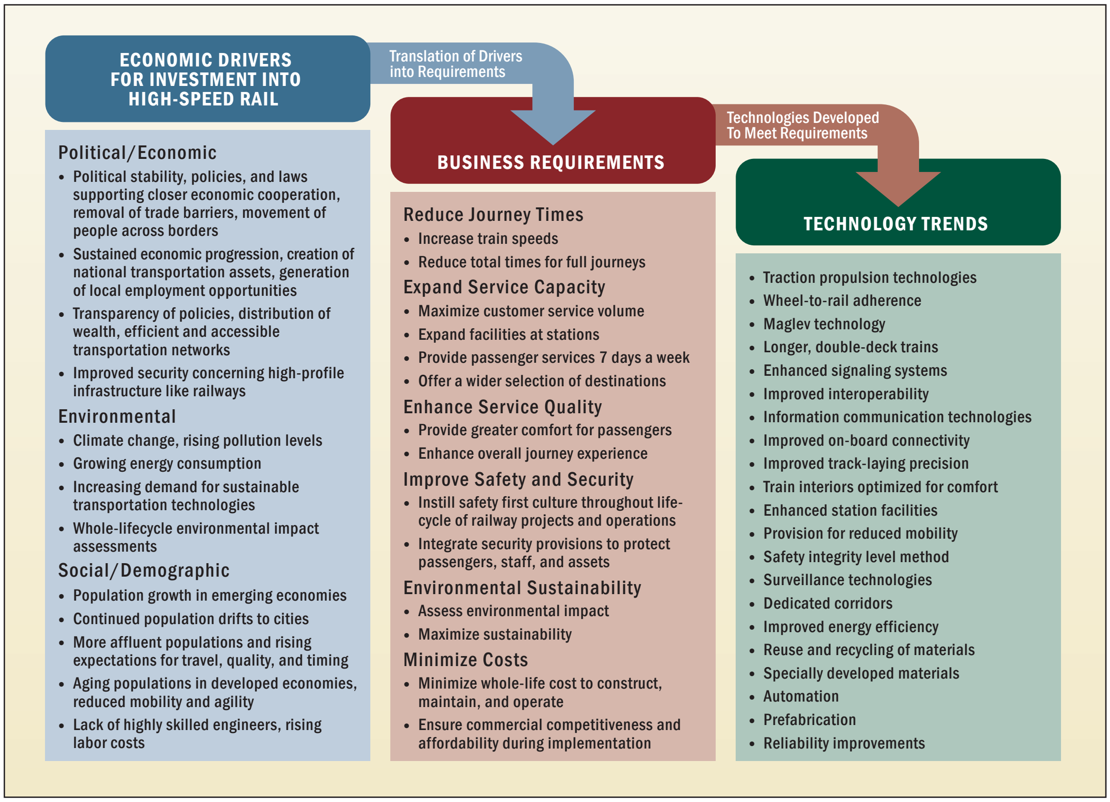


Figure 1. Timeline for High-Speed Rail Development



ECONOMIC DRIVERS FOR INVESTMENT INTO HIGH-SPEED RAIL

Political/Economic
- Political stability, policies, and laws supporting closer economic cooperation, removal of trade barriers, movement of people across borders
- Sustained economic progression, creation of national transportation assets, generation of local employment opportunities
- Transparency of policies, distribution of wealth, efficient and accessible transportation networks
- Improved security concerning high-profile infrastructure like railways

Environmental
- Climate change, rising pollution levels
- Growing energy consumption
- Increasing demand for sustainable transportation technologies
- Whole-lifecycle environmental impact assessments

Social/Demographic
- Population growth in emerging economies
- Continued population drifts to cities
- More affluent populations and rising expectations for travel, quality, and timing
- Aging populations in developed economies, reduced mobility and agility
- Lack of highly skilled engineers, rising labor costs

BUSINESS REQUIREMENTS

Reduce Journey Times
- Increase train speeds
- Reduce total times for full journeys

Expand Service Capacity
- Maximize customer service volume
- Expand facilities at stations
- Provide passenger services 7 days a week
- Offer a wider selection of destinations

Enhance Service Quality
- Provide greater comfort for passengers
- Enhance overall journey experience

Improve Safety and Security
- Instill safety first culture throughout life-cycle of railway projects and operations
- Integrate security provisions to protect passengers, staff, and assets

Environmental Sustainability
- Assess environmental impact
- Maximize sustainability

Minimize Costs
- Minimize whole-life cost to construct, maintain, and operate
- Ensure commercial competitiveness and affordability during implementation

TECHNOLOGY TRENDS
- Traction propulsion technologies
- Wheel-to-rail adherence
- Maglev technology
- Longer, double-deck trains
- Enhanced signaling systems
- Improved interoperability
- Information communication technologies
- Improved on-board connectivity
- Improved track-laying precision
- Train interiors optimized for comfort
- Enhanced station facilities
- Provision for reduced mobility
- Safety integrity level method
- Surveillance technologies
- Dedicated corridors
- Improved energy efficiency
- Reuse and recycling of materials
- Specially developed materials
- Automation
- Prefabrication
- Reliability improvements

Figure 2. Integrated Relationship Between Economic Drivers, Business Requirements, and Technology Trends

Economic drivers have led to the specification of a number of top-level business requirements for HSR lines.

These economic drivers have led to the specification of a number of top-level business requirements for HSR lines. Specifically, future HSR lines must:

- Reduce journey times
- Expand service capacity and choice of destinations
- Enhance service quality, comfort, and reliability
- Improve safety and security
- Achieve environmental sustainability
- Minimize costs

Figure 2 illustrates the integrated relationship between the broad economic drivers, the business requirements for future HSR lines, and the role of emerging technologies in helping to deliver these requirements.

TECHNOLOGY TO DELIVER BUSINESS REQUIREMENTS

Overview

This section introduces the process for assimilating the business requirements for future HSR lines and discusses the emerging technological developments that promise to help deliver these requirements. However, technology alone can go only so far. A holistic approach is necessary, starting with leaders who have the required technical competence to understand the full spectrum of railway issues and the possibilities offered by new technologies. These leaders, in turn, have to select the right people; introduce sound work processes and their controls; and integrate cross-disciplinary input from railway engineering, operational, and commercial expertise throughout all project phases—from specification development through design, procurement, construction, testing, and commissioning. Thereafter, the project leaders must successfully hand the finished product over to a long-term operation and maintenance organization.

Throughout this entire process, it is essential to use systems engineering to capture the stated business requirements for complex HSR projects and translate them into a set of tasks that can be managed to completion under a carefully controlled, evidence-based technical assurance regime. The emerging technologies that can best assist in satisfying the business requirements must be clearly tracked into the design process and then evaluated to test for their effectiveness in delivering the desired project outcomes.

Reduce Journey Times

Train speeds have been increasing over the past 40 years, and this trend is expected to continue over the next 20. The current speed record for a conventional high-speed train, set by a French TGV, is 574 km/h (357 mph).

Faster traction propulsion technologies and improved wheel-to-rail adherence (resulting from more precisely engineered track forms) should enable train speeds to reach 700 km/h (435 mph) by 2030. These speeds will bring the journey times of future rail travel closer to those of commercial air travel. Market data shows that higher speeds resulting in shorter journey times encourage passengers to switch from personal road vehicles and short-haul flights to rail. For example, following the opening of the TGV line between Paris and Lyon in 1983, air service between the two cities was discontinued because of the large passenger swing from air travel to the new HSR line. In the UK, the West Coast Route Modernization and High Speed 1 projects have resulted in a similar increase of market share for rail operations over personal road vehicles and short-haul flights. Parallel trends have also emerged in other Western European countries where new passenger rail lines have recently entered service.

Computer-based train control allows trains to operate safely at closer, controlled, headways and higher speeds, thereby making the best use of the installed trackside infrastructure.

In Japan, China, and Germany, magnetic-levitation (maglev) railway technology has been under development for the past two decades. Commercial maglev operation recently commenced in Germany, the Middle East, and China. However, although a Japanese maglev test train has reached speeds of 581 km/h (361 mph), the investment in dedicated infrastructure for such technology has not yet proved as commercially viable as for conventional HSR technologies.

Overall rail journey times can be reduced further by alleviating existing service bottlenecks. For example, double platforms at stations, supplemented by closer crew management, can reduce unnecessary dwell times. Similarly, good interchanges and quick, easy, and certain connections under weatherproof covers can improve the safety, comfort, and speed of passenger movement between trains and to other forms of transportation.

Looking more radically toward a major step change in journey speeds in the distant future, the US Department of Defense has tested manned rocket sleds that ride on rails and have reached speeds of 1,017 km/h (635 mph) under controlled experimental conditions.

Expand Service Capacity and Choice of Destinations

Train journeys over existing routes have traditionally been constrained by the lack of capacity to accommodate growth in demand. It is now necessary in most countries to expand the capacity of existing networks and increase the range of destinations for passengers. This can be accomplished in part by using advanced technologies such as computer-based train control (CBTC), which allows trains to operate safely at closer, controlled, headways and higher speeds, thereby making the best use of the installed trackside infrastructure. Such technologies have become increasingly reliable in recent years. **Figure 3** provides a schematic overview of a typical advanced signaling technology for train control.

Each train using CBTC technology transmits its identity, location, direction, and speed to dedicated regional control computers. These computers use this information to calculate safe braking distance curves between trains and then transmit the results, along with the speed and distance of the preceding train, back via secure radio transmissions. This process is done continuously to maintain safe distances between fast-traveling trains for them to slow down and stop.

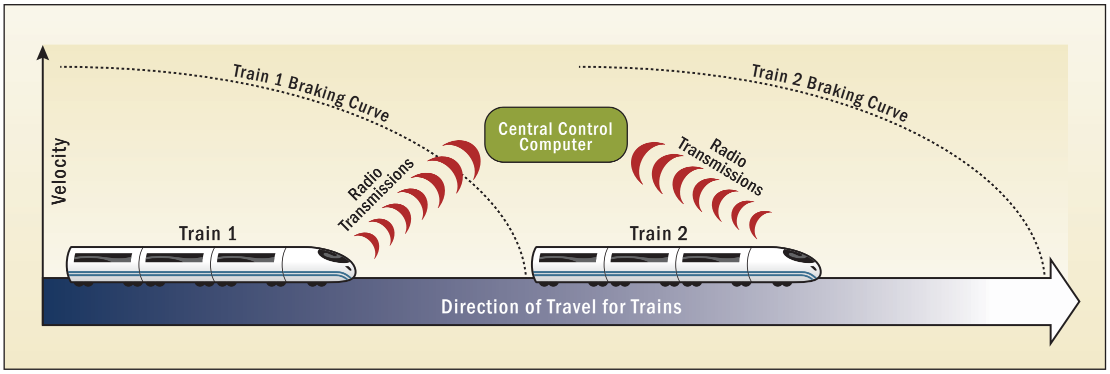


Figure 3. Schematic of Advanced Train Control Technology

CBTC also facilitates the implementation of other advanced means of expanding service capacity such as automatic reversing at sidings and terminal stations as well as bi-directional running over the trackside infrastructure available for service operations during temporary restrictions. Even more sophisticated forms of CBTC offer the future possibility of remote train operation (RTO), with minimal driver intervention, for HSR service.

Greater political and economic cooperation among nations will increasingly favor HSR as a means of moving people between countries more quickly. For example, the European Union (EU) has established Interoperability Directives for implementation under the European Rail Traffic Management System (ERTMS) initiative. This initiative requires the EU member countries to engineer new HSR lines and upgrade existing routes in a standardized manner to enable easier and faster movement of trains across Western Europe. The European Train Control System (ETCS) is a new signaling, control, and train protection system being developed to facilitate this standardization. A series of Technical Specifications for Interoperability (TSIs) are already stimulating considerable technological development from the railway equipment suppliers. These TSIs encourage development of technologies that can allow future high-speed trains to travel over new high-speed lines as well as existing upgraded tracks, albeit at lower speeds dictated by historical route layout constraints.

Train service over congested routes, at major junctions, or close to large cities can be somewhat constrained. Future developments in computer-based traffic management and service regulation technologies will allow optimum use of existing railway infrastructure by enabling train movements against predetermined, timetabled priorities. Where funding, space, and development planning permissions exist, high-speed trains can also avoid existing congested routes via dedicated bypass routes.

Looking further ahead, dedicated new infrastructure can be built to accommodate double-decker trains, as has already been done successfully on Taiwan's high-speed lines. Such trains can provide much higher passenger-carrying capacity over long distances.

Because increases in total service capacity are integrated among trains, infrastructure, and stations, train service enhancements need to be carefully modeled and taken into consideration in providing station facilities and adequate space.

Enhance Service Quality, Comfort, and Reliability

Technology promises to contribute significantly to improving the total "journey experience" for future HSR customers.

Advances in information communications technology will enable travelers to receive service updates and query the status of onward connections (including with other transport modes) directly on their personal hand-held mobile phones before they leave home. These same technological advances will improve the connectivity of personal phones on trains within dedicated compartments, as well as enable on-board electronic mail and other Internet transactions. Wireless repeater units aboard trains will allow passengers to use their personal mobile phones, handsets, and laptops to establish external voice and data connections.

The overall ride quality of trains is set to be improved by technological developments in more-precise track-laying equipment as well as further improvements to maintenance of the wheel-to-rail interface.

Coupled with more reliable air conditioning and lighting, transatlantic-flight-style seating layouts will further enhance the overall comfort levels of fast-traveling trains. Such layouts are already undergoing successful trials in Japan and Korea. Added to this are technological advances in on-train entertainment and amenities that will raise comfort levels on long train journeys to the standards already provided by high-quality airline operators.

Stations, as an integral part of the total journey experience, will need to be friendly and provide easy, convenient access to service information and onward connections, including details of potential weather impacts. In particular, technology will cater to providing better access for passengers with reduced mobility and to making tickets easier to purchase from home, at the workplace, at the airport, or within the shopping mall, as well as at existing railway stations.

Higher performance equipment, less prone to unplanned failures, will improve the reliability of HSR service. In addition, better regulation of train service and faster recovery to timetabled operations following service perturbations will help railway operators and maintainers minimize the impact of unforeseen delays on passengers.

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Improve Safety and Security

Railways are inherently one of the safer forms of travel. Statistically, both railways and airlines provide the safest forms of transportation in terms of the number of injuries or fatalities recorded over the distance traveled.

A combination of technological improvements and better work processes will further improve the safety of HSR travel. New design, construction, and maintenance technologies are being applied that allow railways to be engineered, built, maintained, and operated with the highest safety principles in mind. While improved protection technologies actively prevent construction hazards from affecting workers, advances in automation technology will reduce the amount of manual labor required, making both worksites and maintenance activities safer. In addition, better crash protection and response to other critical safety hazards are at the core of modern rolling stock, infrastructure, and station designs.

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The application of high-integrity, safety-critical software to control the movement of trains is just one example of technological innovation for improved HSR safety. Such software is developed in a highly controlled programming structure and rigorously validated and tested to prove compliance with a defined Safety Integrity Level (SIL) before it is released for operational use to enhance the safe movement of passenger-carrying trains.

Security measures against planned malicious activity have increased significantly in recent years. Both the global aviation and railway industries have become high profile and, regrettably, key publicity-attracting targets for the wrong reasons. In response to this threat, a new generation of security technologies has started to emerge. These range from more traditional remote surveillance and blast prevention equipment to highly sophisticated movement, facial, voice, and tactile recognition systems. State-of-the-art "threat anticipative technologies," supported by improved surveillance and containment through planned engineering designs, will seek to mitigate the identified risk exposures.

Advances in track trespass deterrent technology also enable operators to protect their infrastructure from theft, vandalism, and sabotage. Greater use of uninterruptible power supply (UPS) technologies will protect safety and security critical systems from the eventualities of power outages due to accidental, intentional, or natural events.

Achieve Environmental Sustainability

Future high-speed lines will require the large-scale construction of linear infrastructure across long geographical areas. This use of land and the environmental impact of future service operations must be assessed carefully and appropriate mitigation measures developed and implemented to maximize the chances for longer-term sustainability.

Advances from all technology fields will contribute to the environmental sustainability of HSR. For example, not only are light-emitting diodes (LEDs) being installed in new rolling stock, but they will also provide lighting in stations, tunnels, and other infrastructure in the future. This is just one example of how new technologies will help minimize the whole-life cost (WLC) of high-speed railway lines, infrastructure, and rolling stock.

It is also important to carefully manage heritage buildings to minimize damage to or loss of historic properties. Failure to do so can cause public concern and have a negative impact on railway construction activities. When it is necessary to work around sensitive buildings, a series of advanced monitoring sensors have been developed to monitor sound, vibration, temperature, and settlement during construction.

Figure 4 illustrates how the use of rail travel can reduce detrimental emissions, compared to a sample of other forms of mass transportation.

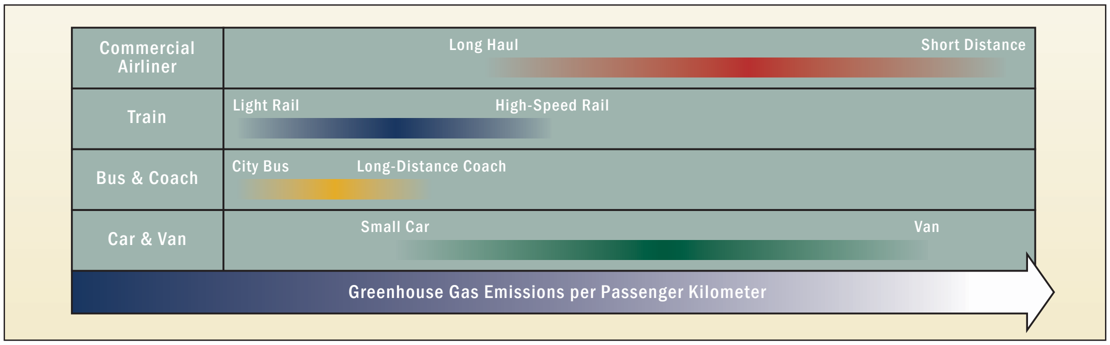

Figure 4. Comparative Emissions, by Transportation Mode

The routes for future high-speed lines clearly need to be planned in a manner that minimizes adverse environmental impact. One way to achieve this is by using dedicated corridors of land next to existing railway lines, water canals, or road highways, as depicted in **Figure 5**.

Technological developments on future HSR lines include the use of more fuel-efficient, lower-emission train propulsion equipment as well as hybrid fuel technologies that combine diesel engines and batteries to provide a potentially more efficient means of powering a train. These technologies can provide useful backups to electricity as the base source of motive energy. Energy efficiency can also be further improved by making maximum practical use of regenerative braking technologies.


Above:
Incheon International Airport Railroad, Korea (green), parallel to existing motorway (yellow)

Left:
Construction work for High Speed 1, UK (red), underway along an established transportation corridor (blue)

Figure 5. Examples of Using Existing Transportation Corridors for Railways

Technological sustainability developments in railways also extend to the trackside infrastructure. For example, high-performance track sleepers made from recycled plastic are now being tested and are becoming available for use.

Minimize Costs

The cost to build and operate high-speed lines needs to be kept to a minimum. A WLC approach is necessary to obtain the best tradeoff among the up-front capital cost solutions and their implications for the longer-term impact on railway operations and asset maintenance.

The simplified diagram in **Figure 6** shows how typically 85% of the WLC for major rail projects is committed during the early stages when requirements are defined and concepts are designed. It is critical at these early stages to review the requirements and proposed design solutions in detail. This review is best conducted in the form of well-structured, cross-disciplinary workshops that cover every aspect of the project from development through revenue service operations. Such structured workshops can be managed by trained practitioners using value engineering (VE) techniques. It is important to use a structured systems engineering approach to carefully trace the VE cost-reduction opportunities back

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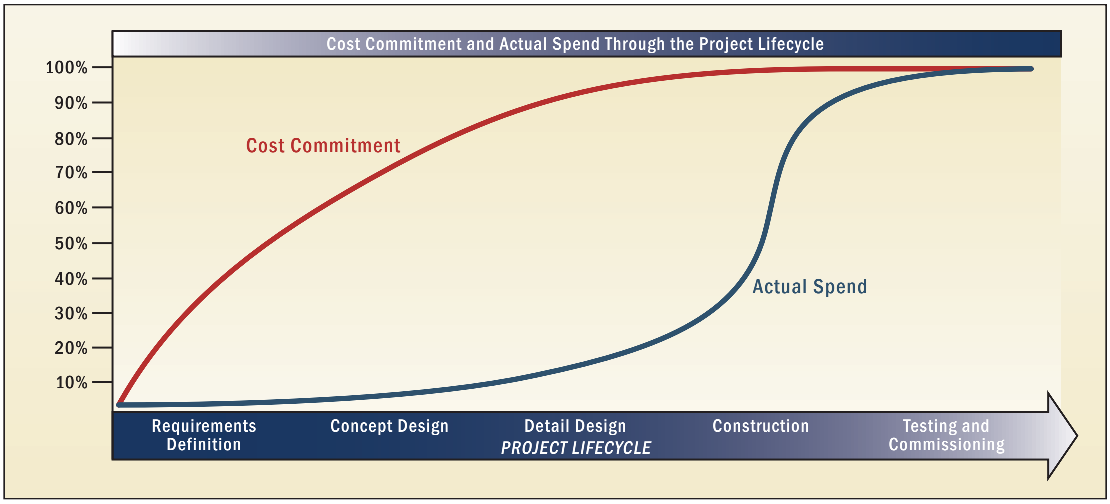

Figure 6. Simplified Diagram Showing Commitment of Costs at Each Stage of the Rail Project's Lifecycle

Technology can help reduce capital costs by automating routine engineering tasks, introducing modularized construction technologies, and incorporating the use of precast and preassembled components that allow maximum off-line testing.

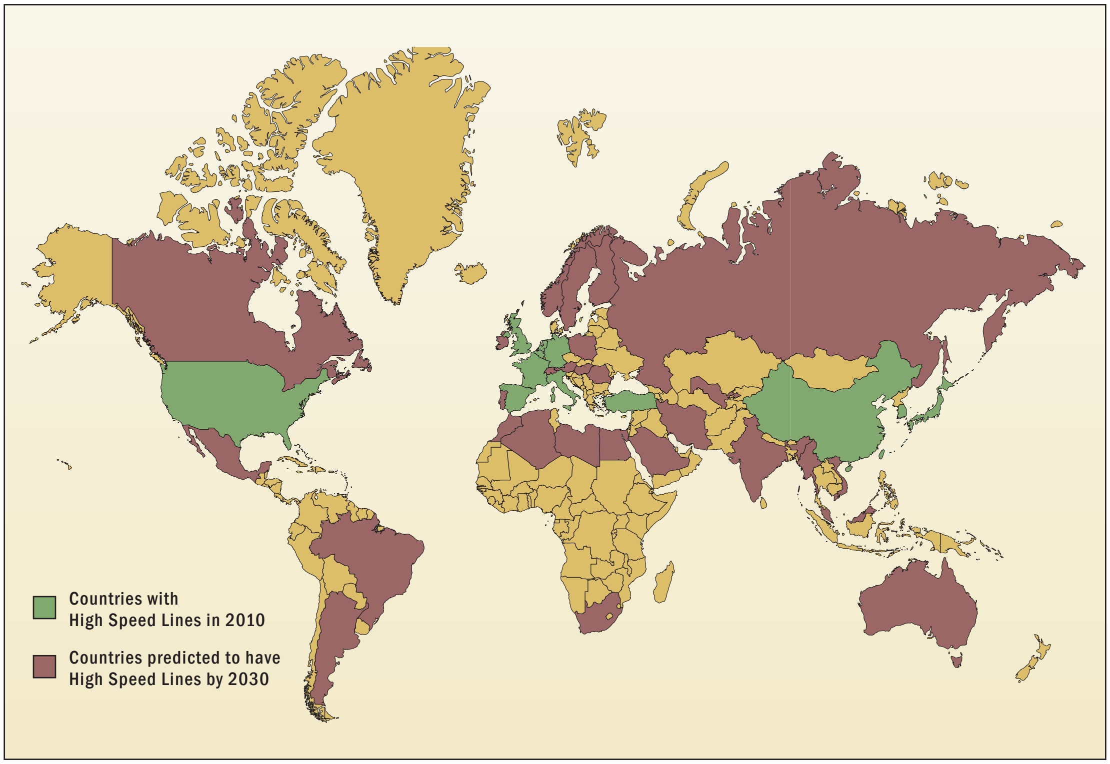

Figure 7. High-Speed Rail (>250 km/h [>155 mph]) Prediction by 2030

to the business requirements to confirm that the overall project objectives are still being met. This approach safeguards the project outputs from being put at risk by cost-reduction measures that do not take into account the total impact on the project throughout its lifecycle.

Technology can help reduce capital costs by automating routine engineering tasks, introducing modularized construction technologies, and incorporating the use of precast and preassembled components that allow maximum off-line testing. Similarly, technology can assist in reducing the cost of operating and maintaining railway assets by providing a new generation of trackside assets that deliver higher mean times between failures (MTBFs). More reliable equipment, coupled with planned maintenance regimes, requires less operator intervention. Features such as remote condition monitoring, improved ease of access to assets and their renewal, and design solutions that promote maximum energy efficiency during revenue operations all represent further technological cost-reducing contributions.

The cost of designing and manufacturing rolling stock can be minimized through a careful platform design strategy that uses standardized components compatible with a multitude of other systems. New or custom-made products can be designed by combining these standard components, thereby minimizing design costs and realizing manufacturing economies of scale.

FUTURE HIGH-SPEED RAIL NETWORKS

HSR networks are currently concentrated in Europe and the Far East. The US also has a single high-speed line, along its northeastern seaboard. However, a larger pool of nations is now engaged in planning for HSR. As illustrated in **Figure 7**, by 2030, the number of countries with HSR lines is predicted to have grown significantly.

Although HSR networks currently dominate in China, Japan, and Europe, it is worth noting that lines outside the latter two regions only started appearing in the past 10 years, indicating that HSR is still an emerging technology when considered worldwide. Indeed, most high-speed line construction today is being undertaken in regions where HSR is already established. China is implementing its projects at a striking pace, with plans to extend the current network by another 34,000 km (21,100 mi), 10,000 km (6,200 mi) of which will be high speed. Indeed, the services on China's current network of dedicated high-speed lines have proven popular enough to drive domestic airlines out of business on the routes concerned.

The second largest number of high-speed lines under construction worldwide have the goal of strengthening the trans-European HSR network, as shown in **Figure** 8.

In addition to Western Europe, Turkey is currently building high-speed lines planned to extend the national network to 4,000 km (2,500 mi) by 2025.

Among the numerous concepts for new high-speed lines elsewhere are:

- ***United States***—Plans for regional networks such as California's proposal for HSR between Anaheim and San Francisco and, on the East Coast, plans to expand the existing Boston–Washington, DC, line into an entire network
- ***South America***—Two nations with HSR plans: Brazil between Rio de Janeiro, São Paulo, and Campinas and Argentina between Buenos Aires and Córdoba
- ***Africa***—Feasibility studies for HSR in Egypt and South Africa; more mature plans in Morocco and Algeria

Technical solutions ensuring the viability of these plans, such as high travel speeds and interoperability, require further development to mature. However, given the relative infancy of worldwide HSR, it would appear that this development will be a natural consequence of an accelerated global investment in HSR.

Although many proposals plan to employ existing HSR technology, the current diversity has set off competition among national formats, especially in Europe, and, at the same time, led to focusing on interoperability efforts. The anticipated fast expansion of HSR worldwide is likely, therefore, to be accompanied by technological advancements in a competitive environment, thus rapidly displacing conventional boundaries.

Though local political and economic drivers may lead to the cancellation, delay, or acceleration of each individual proposed scheme, it is clear that HSR, as a technology and as a transportation mode, is gaining momentum worldwide and is entering an era of rapid development and expansion.

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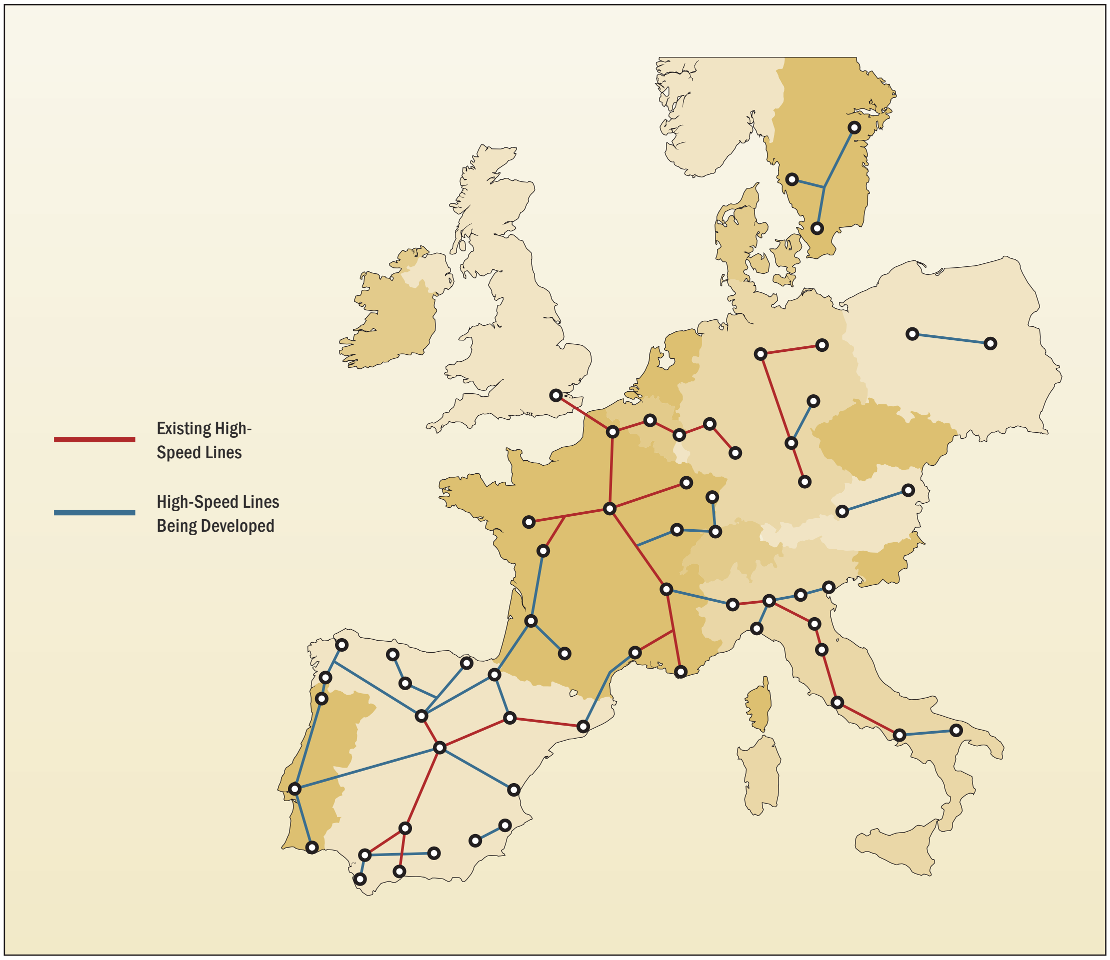

Figure 8. Current and Planned High-Speed Lines in Western Europe

CONCLUSIONS

In recent decades, HSR projects have experienced significant growth in many parts of the world. The next 20 years are expected to see a major increase in the number of high-speed lines globally as the broader economic drivers in most regions favor an accelerating shift toward this form of mass transportation. The emerging new railway technologies will help meet the growing expectations of railway customers, which are captured in the form of a structured set of business requirements. These emerging technologies will also help stimulate the economic case for future investments in HSR.

The considerable investment of capital funds necessary to construct HSR lines and the longer-term costs of operating and maintaining the assets are normally offset by a combination of factors: (1) a far greater return on investment through revenues, (2) a less-adverse impact on the environment compared to most other forms of transport, and (3) the substantial social benefits associated with connecting cities via a high-quality transport infrastructure.

Technology will always play a key role in railways by helping to meet the growing expectations reflected in a number of the criteria discussed in this paper. Technological developments will help to cut costs, reduce risks, and make railways more commercially competitive than most other forms of mass transportation.

The broad economic drivers and supporting business requirements for future HSR will be addressed by a range of technologies that are already in advanced development. As technology becomes more central to the growth of HSR networks in many parts of the world over the next 20 years, so too does the need to invest in the management and technical skills that will help harness these opportunities to successfully deliver the growing number of emerging rail projects. ■

BIOGRAPHIES

Siv Bhamra, PhD, has 29 years of experience in the project management and engineering of major rail projects. He has worked on the full spectrum of rail projects—from light rail, urban metros to high-speed lines—engaging in activities ranging from conducting feasibility studies to implementing full schemes. Siv has delivered rail projects in Europe and the Far East and has performed studies for rail operators in the US, Middle East, and South Asia. His numerous technical achievements include developing solid-state traction inverting substations to save energy, implementing advanced train control technologies to improve the performance of existing and future railways, and conducting research into state-of-the-art security management systems.

Siv's understanding of risks and the formal assessment of work processes and technologies that can contribute to catastrophic failures, along with the consequential implications, has put him at the forefront of promoting robust operational safety-case regimes and implementing safety-focused cultures in the lifecycles of major projects.

Siv joined Bechtel in 1999 while on the Jubilee Line Extension Project in London. Before that, he had worked in senior roles with London Underground and a number of other railway companies. He was also the principal transportation advisor to the European Bank for Reconstruction and Development for 2 years. Currently, as the delivery director for Bechtel on the Crossrail project in London, he manages technical functions, supervising the work of some 2,000 engineers and overseeing the delivery of all systems works on this landmark project.

Elected a Bechtel Fellow in 2004, Siv is a member of five professional institutions and three technical societies. He won the Enterprise Project Manager of the Year Award in 2006, the London Transport Award in 2004, and a Safety Management Award in 2004, and has twice been accredited with further awards of technical excellence (1984 and 1986). He is also a leader in business process improvement initiatives and is an accredited Six Sigma Champion.

Siv was recognized for his efforts in restoring the Piccadilly Line to passenger service following the terrorist attacks in London in 2005, commended for his work to recover operational service on the Northern Line following a derailment in 2003, and honored for his courage during a major fire at Kennington Station in 1990.

Siv is Bechtel's management representative to Loughborough University, a guest lecturer to several universities, and a respected transportation security specialist and advisor. He has presented at several conferences and has written numerous papers on management and technical disciplines.

Siv has a PhD in Railway Systems Engineering from the University of Sheffield, South Yorkshire; an MBA in Project Management from the University of Westminster, London; and an MSc in Engineering Design from Loughborough University (all in the UK).

Maximilian Fieguth is a highly regarded engineer in Bechtel with a growing reputation. He joined the company in 2008 and participated in the final delivery stages of High Speed 1, the UK's first high-speed line connecting London via rail to European mainline destinations through the Channel Tunnel.

Maximilian is currently a mechanical engineer on the Crossrail project. He looks after the quality, integration, and standardization of the output of various design consultants and provides design management leadership as part of the Engineering Directorate.

Maximilian has also served in the Engineering section of Bechtel's Civil Global Business Unit, where he supported the company's work internationally. He is a Six Sigma Yellow Belt and a member of Bechtel's and Crossrail's NextGen groups, which provide a forum for engaging with emerging engineers of the future.

Maximilian received a master's degree in Mechanical Engineering from Imperial College London and is an Associate of the Institution of Mechanical Engineers in the UK.