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Formulating a Strategy for Securing High-Speed Rail in the United States

MTI Report 12-03

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REPORT 12-03

FORMULATING A STRATEGY FOR SECURING HIGH-SPEED RAIL IN THE UNITED STATES

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16. Abstract

This report presents an analysis of information relating to attacks, attempted attacks, and plots against high-speed rail (HSR) systems. It draws upon empirical data from MTI's Database of Terrorist and Serious Criminal Attacks Against Public Surface Transportation and from reviews of selected HSR systems, including onsite observations. The report also examines the history of safety accidents and other HSR incidents that resulted in fatalities, injuries, or extensive asset damage to examine the inherent vulnerabilities (and strengths) of HSR systems and how these might affect the consequences of terrorist attacks.

The study is divided into three parts: (1) an examination of security principles and measures; (2) an empirical examination of 33 attacks against HSR targets and a comparison of attacks against HSR targets with those against non-HSR targets; and (3) an examination of 73 safety incidents on 12 HRS systems.

The purpose of this study is to develop an overall strategy for HSR security and to identify measures that could be applied to HSR systems currently under development in the United States. It is hoped that the report will provide useful guidance to both governmental authorities and transportation operators of current and future HSR systems.

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EXECUTIVE SUMMARY

As part of the Mineta Transportation Institute's (MTI's) continuing research effort on high-speed rail (HSR) security and safety, this report presents an analysis of information relating to attacks, attempted attacks, and plots against HSR systems.

While terrorist attacks aimed at trains and buses have increased over the past several decades, very few attacks have targeted HSR. To gain possible insights into the consequences of successful terrorist attacks against HSR, this inquiry includes accidents and other HSR incidents that have resulted in injuries, fatalities, or extensive asset damage. The authors also reviewed security at selected HSR systems in Europe and Japan to identify measures that could be applied to HSR systems currently under development in the United States. These three lines of inquiry are used in this report to develop an overall strategy for HSR security.

PART I—SECURITY PRINCIPLES AND MEASURES

Almost any discussion of security causes many HSR proponents to bristle. They worry not only that mere mention of the issue will invite proposals for security regimes or heavy-handed government edicts that will interfere with fast, convenient rail travel but that even talking about terrorist threats might somehow undermine campaigns to win support for new HSR systems.

However, The subject of security need not create adversaries, and the right time to initiate a discussion is now, as new HSR systems are being designed and built. This report is intended to inform that discussion by addressing the following questions:

1. Does HSR Merit More Security or Different Security Measures than Other Passenger Rail?

HSR creates opportunities to improve security. Like airports, most railway stations were built decades before security became a major concern and had to be modified and retrofitted for security. HSR expansion in the United States will bring about the construction of new stations, right-of-ways (ROWs), and rolling stock and therefore represents an opportunity to design and build in security at the beginning.

Some argue that HSR merits more security, for a number of reasons. They contend that HSR is an iconic target, making it more attractive to terrorists than non-HSR. It is true that visually and symbolically, HSR trains are much like the streamliners and famous named passenger trains of the 1930s and 1940s. But new Metro lines are also modern in looks and have an iconic quality. As high-speed trains become more common and operate simply as faster commuter trains, their iconic premium will diminish.

It is also argued that derailed high-speed trains would result in more casualties. The data show that HSR derailments can be disastrous, but the average number of casualties in the data is driven by just two accidents and one case of sabotage.

HSR trains carry an elite passenger load. True now, but this feature will diminish as HSR becomes more common and serves growing numbers of ordinary commuters.

Finally, the construction of HSR systems could provoke opposition from some members of local communities who might be tempted to take disruptive action. HSR systems may face local opposition from those who may see them as threats to their local community. In Europe, anarchists and malicious pranksters have disrupted HSR.

But HSR also has characteristics that make it less attractive to terrorists. Passenger loads on HSR trains, per car and per train, are typically less than those on slower-speed commuter or intercity trains, reducing the chances of replicating the high body counts achieved in the worst terrorist attacks on such systems.

Reservations and advance ticket sales for HSR travel create opportunities for identity checks. Unlike regional or commuter rail, HSR usually has all-reserved seating, which requires making an advanced booking. However, this practice may not be followed where HSR serves as commuter rail.

Exclusive HSR ROWs, often fenced, hard roadbed, and seamless rail construction reduce the vulnerability of the tracks to unauthorized intentional access and increase the chances of detection of sabotage.

2. Is it Appropriate to Consider Reducing Security for Passenger Rail?

If the expansion of HSR offers an opportunity to examine security enhancements, it should also be an occasion to have a sensible discussion about risk to all rail passengers—HSR and non-HSR. Security should not become a ratchet where the current level becomes the norm and can only be increased.

In the past 40 years, only one person in the United States died as a consequence of a terrorist attack on a rail target—the 1995 derailment of the Sunset Limited. Nevertheless, the long-term increase in the number and lethality of terrorist attacks on trains and buses worldwide argues for continued security measures. Between 9/11 and December 31, 2012, 2,190 terrorist or serious criminal attacks were made against public surface transportation, resulting in 4,304 fatalities. Of these attacks, 870 were against rail targets, resulting in 1,362 fatalities.

In addition to those attacks, 15 terrorist plots that we know about against rail passengers either failed or were foiled by authorities. While most of these plots were interrupted in their early planning stages, they were intended to kill in quantity.

Just as it is hard to make the case that HSR requires more security than non-HSR, it is difficult to argue that HSR requires less security. An argument can be made that some of the security measures currently in place for all passenger rail are unnecessary, but that is an argument about rail security in general, not about the differences between HSR and non-HSR.

3. What Threats Drive Security Concerns?

Security for passenger rail is driven by both actual and anticipated events:

- Improvised explosive devices (IEDs) detonated on board trains or at stations
- An active shooter or multiple shooters on board a train or at stations
- Attempts to derail trains by sabotaging the tracks with IEDs, using mechanical means, or placing obstacles on the tracks
- Disruption of traffic by attacking cables or signaling systems, bomb threats, or other means

4. What Can Be Learned from HSR Security in Europe and Japan?

Special security measures are in effect for the Eurostar trains that run between London and Paris and Brussels. These measures initially reflected concerns about the terrorist campaign being conducted by the Irish Republican Army (IRA), which was active in the United Kingdom (UK) during the construction of the tunnel under the English Channel. Preventing illegal immigration to the UK is also an important concern.

Terminals for the Eurostar have dedicated platforms, separated from the stations' other platforms. Eurostar passengers enter through a special entrance inside the station, where luggage is x-rayed and passengers are screened. Passport control and customs inspections are completed at the boarding station so that upon arrival, passengers merely disembark.

Other high-speed trains are treated the same as ordinary passenger trains—there is no passenger or luggage screening or other security checks, even for cross-border trains, although random ticket or ID checks can occur on board some trains. Countries within the Schengen space operate on the principle of free circulation and reflect the general attitude that without new technologies that do not yet exist, any form of passenger screening would delay travel times and, given current threat assessments, are unwarranted.

Passengers on some high-speed trains must have their ID confirmed, and their baggage is scanned. Selected passengers may be subjected to a personal search. Spain also has ticket controls at the platform entrance.

German authorities have not mandated passenger or luggage screening for HSR trains. Germany has no dedicated high-speed corridors or platforms, so HSR is fully integrated into the national rail system, making it virtually impossible to separate HSR from non-HSR passengers. Germany relies primarily on surveillance, utilizing both uniformed guards and closed-circuit television (CCTV) at train stations.

Following the terrorist bomb attacks on London's tube in 2005, British officials carried out trials to test the feasibility of mass passenger screening. They found that while riders were

generally positive about the need for security, they were unwilling to accept major delays or the loss of privacy that came with screening. Despite the continuing high terrorist threat level, the Department of Transport concluded that airport-style screening of all rail and underground passengers was not possible with the technology available.

European countries—in particular, the UK, France, and Germany—make extensive use of CCTV. In addition, armed police are deployed at train and subway stations and on the trains. New stations such as the station in Avignon, France, and the stations along the new Meteor Metro line in Paris, are designed to facilitate surveillance. They have open spaces, have no dim corners, and are well lit.

As for track security, HSR ROWs are fenced along their entire length. Level crossings are not permitted. Bridges over the lines have sensors to detect objects that fall or that may be thrown onto the tracks. In the 1990s in France, early-morning sweeper trains were dispatched before passenger traffic began.

There are no screening procedures for passengers boarding high-speed or other trains in Japan. After the 1995 sarin attacks on Tokyo's subways, CCTV surveillance was increased and surveillance cameras were installed on board trains to keep passengers "feeling secure."

In sum, with the exception of the Eurostar and some longer-distance trains in Spain, there are no separate security regimes for HSR trains in the European countries or in Japan. HSR trains are generally integrated with non-HSR trains, precluding separate security regimes.

Screening passengers and luggage, even on a random basis, as practiced on some rail systems in the United States, generally has been rejected.

European authorities see the greatest vulnerability in the crowded metro and subway stations and trains. European attitudes about the degree to which risk can be reduced differ from those of Americans. Instead of passenger screening, European rail systems rely on the presence of armed guards and extensive CCTV surveillance. Greater attention is given to designing security into new stations than to passenger screening.

5. What Can Be Learned from Terrorist Attacks on HSR?

MTI's Database of Terrorist and Serious Criminal Attacks Against Public Surface Transportation shows only 33 terrorist attacks on HSR targets, and there are some interesting differences between attacks on HSR and those on non-HSR targets.

The percentage of non-HSR attacks involving bombs is higher than that of HSR attacks, but the percentage of fatalities caused by bombs is lower. Track bombs designed to cause derailments were far more frequent and far more lethal in HSR attacks than in non-HSR attacks.

The average fatalities per device (FPD) is higher for non-HSR targets (1.7) than for HSR targets (1.1). Despite that, the FPD of track bombs used against HSR targets is higher than that of track bombs used against non-HSR targets. The situation for passenger-compartment bombs is dramatically reversed. The average FPD for these bombs against non-HSR targets is almost three times that of bombs placed in HSR passenger compartments.

The overall lethality rate of terrorist attacks on HSR targets, measured in fatalities per attack, is significantly lower than that for attacks on non-HSR targets.

These poor results, from the terrorists' perspective, suggest that HSR is not likely to be the primary target of terrorists seeking high body counts. Terrorists bent upon slaughter can more easily achieve their goal by attacking crowded subways and commuter trains, as they have done.

The results of a successful derailment of an HSR train could theoretically match those of a successful bombing of a crowded commuter train, but successful high-casualty HSR derailments are rare. Only three of 11 attempted terrorist derailments of HSR trains succeeded, and only one derailment caused by terrorists resulted in casualties of that magnitude. (More details are provided in Part II of this Executive Summary.)

6. What Can Be Learned from Accidents Involving HSR?

Because of the fortunate paucity of attacks on HSR systems, our research was broadened to include data from accidents involving HSR, which could provide additional information about the possible consequences of potential future terrorist attacks and might also offer insights into such attacks. Might terrorists, for example, try to exploit vulnerabilities revealed by HSR accidents in an attempt to replicate them? Although this inquiry was not intended to result in conclusions about safety itself, some conclusions emerged.

There has been, on average, one accident in every three operating years in the 12 countries that have HSR and one fatal accident every 13 years—less than one fatality per operating year.

The overall average is 2.4 fatalities per accident; the median is less than 1. And 101 of the 167 fatalities occurred in a single accident in Germany, when a faulty wheel on a high-speed train led to a disastrous derailment that hurled coaches into an abutment.

The most common accidents were collisions with vehicles at grade crossings—nine incidents, two of which resulted in train derailments and a total of nine fatalities (seven in the vehicles).

The most lethal events, on average, were the derailments. Of seven derailments, two were disasters. The one in Germany and one in China that resulted in 40 fatalities account for 91% of the fatalities. These two events, however, added to the two HSR derailments caused by terrorists in Russia, one of which killed 27 people and injured 95 and the other of which injured 60 people, may lead to terrorist perceptions that one way to achieve high

body counts is by derailing high-speed trains. This is what Osama bin Laden may have had in mind when he urged followers to derail passenger trains in the United States. (More details on accidents are provided in Part III of this Executive Summary.)

7. Should HSR Passengers Go Through Security Screening?

Should all HSR passengers undergo screening like that of passengers boarding the Eurostar, or should they board as other rail passengers do now?

There are a number of options for HSR security screening:

1. An aviation-security model that involves the rigorous screening of all HSR passengers and their carry-on baggage for weapons and explosives.

2. An option that might be called “aviation security lite,” such as a Eurostar equivalent. In such a model, 100% of HSR passengers would be screened but would undergo a less-rigorous inspection.

3. Subjecting HSR passengers to the same measures as those currently used for some non-HSR passengers. These include ID checks, explosives-detecting canines, and, most important, “selective” passenger screening in which passengers are randomly selected for voluntary screening.

4. A purely theoretical but unlikely fourth option: The expansion of HSR systems in the United States could be the occasion for a fundamental reassessment of risk, leading to an overall reduction in all passenger rail security—for example, by eliminating any attempts at passenger screening.

Imposing an aviation-security model on HSR passengers would be difficult and is unnecessary. Very small quantities of explosives that can cause catastrophic airliner crashes if smuggled on board cannot derail a train or cause catastrophic train crashes. The same is true of firearms and other weapons. One can theoretically hijack a train, but one cannot crash it into the side of a skyscraper. Weapons pose a danger to passengers on board, but no more of a threat than that to persons at any other public venue.

Adopting 100% screening would have implications not only for passengers and screeners but also for station design and construction, location of vendors at stations, even train schedules. Screening must be carried out not only at a train’s initial departure point but also at every stop along the entire route. This would require all boarding passengers to pass through checkpoints at some point. It also would require the physical isolation of HSR passengers from unscreened, non-HSR passengers.

All other entrants to the secure area would also have to be screened, and any security breaches would have to be resolved before boarding is permitted. In a rail system, this could cause delays along the entire route.

Maintaining a separate security regime for HSR passengers would impede the integration of HSR with other rail systems and transportation modes as well as the development of HSR trains as commuter rail. Conversely, the smooth integration of HSR with regional, commuter, and rail transit services in large terminals would make it more difficult to impose a separate security regime for HSR passengers.

Imposing a robust passenger-screening regime would also undermine one of the major attractions of HSR, its convenience: Trains run from city center to city center. There are no commutes to and from airports. Passengers can easily bring their luggage on board. There are no security delays. And HSR trains can provide convenient connections with other modes of surface transportation without the need to change stations.

8. Would Increased Security for HSR Offer a Net Security Benefit to Public Surface Transportation?

With finite resources, authorities are obliged to make decisions about the allocation of security resources. Generally, such decisions address threat, vulnerability, and consequences. One additional criterion is whether providing security for a specific target or category of targets offers a net security benefit, that is, does it prevent terrorists from doing something that they cannot do elsewhere with equal ease and similar consequences?

If the security measures have no effect other than obliging terrorists to select other public spaces where they can expect to achieve the same results, there is no net security benefit. For potential targets where the consequences of a successful attack could be catastrophic, pushing terrorists to softer targets where the consequences are likely to be less provides a net security benefit.

Unlike the situation in aviation, keeping weapons and bombs off HSR trains may do little more than shift terrorist sights to ordinary trains and subways, which are already well-established terrorist targets, or still other easily accessible targets outside of the transportation sector. That may be good news for HSR passengers, but it offers virtually no net security benefit to transportation users or society.

9. Where Should HSR Security Efforts Be Focused?

The data do not support the hypothesis that HSR passengers are in greater danger from bombs smuggled on board high-speed trains than other passengers. Given the difficulty of maintaining a separate security regime for HSR passengers (to say nothing about sustaining the moral argument of treating HSR passengers as a special class), it may make more sense to treat all rail passengers as a single class, allocating security resources according to threat, not target category. This would mean putting the focus on the station rather than the train.

Focusing on the station would match current security theory in Europe and Japan, where HSR has become merely another component of an integrated passenger rail system.

If there is an area where HSR merits special attention, it is along the ROW, where terrorists have focused most of their action. Only through derailments can terrorists hope to achieve the high body counts that have become a hallmark of contemporary terrorism. At the other end of the spectrum, disruption of HSR traffic by placing fake devices or obstacles on the tracks has become a mode of protest.

10. What are the Principles of an HSR Security Strategy?

- HSR travel is safe. The most frequent sources of accidental casualties are pedestrians on the tracks and accidents at grade crossings. Terrorists have attacked HSR targets, but not with the frequency or lethality of their attacks on subways and commuter trains.

- The construction of new HSR systems offers an opportunity to review rail security for all connecting rail transportation systems—the goal is passenger security, not just HSR passenger security.

- Preventing attacks is difficult but not the only goal of security. Facilitating emergency response and rapid restoration of service should also be considered.

- Intelligence efforts have been critical in stopping terrorist plots, but they cannot foil every attempt. Physical security measures offer some deterrent value. They can discourage some of the less-competent attackers and complicate planning for the higher-end terrorists.

- Since HSR will be connected to non-HSR systems and in many systems is envisioned to function as high-speed commuter transit, separate, more-stringent security regimes for HSR will be the exception.

- Any special security measures adopted for HSR trains should provide a net security benefit, not merely displace the risk to non-HSR trains and passengers.

- Security measures may focus on the station rather than a particular component of transportation in the station. New or renovated stations should be designed not only to facilitate security but also to accommodate future security environments, including temporary increases in security and developments in security technology.

- Security measures at stations and prior to boarding should anticipate heightened security situations.

- Security resources should be allocated to save lives, not protect one category of trains or passengers.

- An aviation-security model of 100% passenger inspection does not appear feasible with today's technology.

- Random screening for both HSR and non-HSR passengers is used increasingly and appears generally acceptable.

- The apparent propensity of terrorists to attack the rails of HSR lines suggests that rail security measures should be given close attention.

- Disruptions caused by objects on the tracks, false signals, and threats requiring inspections and patrolling also should be considered in security planning.

- Given the importance of train control and signaling in HSR systems, cyber security must also be given appropriate attention.

PART II—TERRORIST ATTACKS ON HIGH-SPEED RAIL

An empirical examination of the MTI Database of Attacks on Public Surface Transportation between 1970 and 2012 reveals the following: (1) There were 33 attacks, in which 32 people were killed, against HSR targets, including trains, tracks and infrastructure; twenty-four (72.7%) of these attacks involved 29 IEDs, improvised incendiary devices, or other explosives, such as mines. Most of the devices were placed on a track or bridge, or in a tunnel. One of them, a 7- to 8-kg (15- to 18-lb) charge, caused the derailment of a high-speed train in Russia, killing 27 people.

There are important differences between these attacks and the 1,510 devices used in 1,283 attacks against non-HSR targets, which include all passenger trains (intercity, subway, etc.), stations, tracks, and other infrastructure.

First, while the percentage of non-HSR attacks involving devices is slightly higher than for HSR attacks, they account for a much lower percentage of fatalities: 76.1% instead of 100%.

Second, comparing the percentage of devices placed on railway tracks, in tunnels, and on bridges to the percentage of those placed in the passenger compartment of trains reveals that track bombs account for 59% of all devices used against non-HSR targets and 76% for HSR targets, while the percentage of devices placed in passenger compartments is roughly the same.

Third, although the overall FPD for HSR attacks (1.1) is lower than that for non-HSR attacks (1.7), the lethality of HSR track bombs is higher (1.2 vs. 0.9); this lethality is slightly higher (9%) than the HSR average and much lower (47%) than the non-HSR average. The situation is strikingly different for passenger-compartment devices. In HSR attacks the FPD is 1.7, whereas it is 4.5 for non-HSR targets; while this is 54% higher than the HSR overall average, the non-HSR FPD is 165% higher than the overall average.

Fourth, devices designed to cause derailments were used far more often in HSR attacks (33%) than in non-HSR attacks (8.9%), and they were considerably more lethal (accounting for 85% of the HSR fatalities, as opposed to 19%).

Overall, the slightly lower lethality of HSR attacks relative to non-HSR attacks suggests that HSR may not be the primary target of terrorists seeking high body counts. However, they could detonate bombs in HSR stations or platforms or attempt HSR derailments, although the rigid coupling of HSR trains makes a successful derailment more difficult to achieve. In addition to focusing on stations, those charged with security should also focus on tracks and supporting infrastructure (electrical supply, overhead wires), where devices could be lethal, or the instruments of low-level attacks aimed at disrupting HSR systems.

PART III—HIGH-SPEED RAIL ACCIDENTS AND THEIR SECURITY IMPLICATIONS

Safety incidents on 12 HSR systems in Western Europe, East Asia, and the United States reveal vulnerabilities and provide insights into to the possible consequences of terrorist attacks. Of 73 HSR safety incidents, 35 resulted in injury or death to passengers, crew, or others. Seventeen resulted in one or more fatalities, for a total of 167 deaths. The two most deadly accidents caused 84% of the fatalities (101 and 40 deaths).

Most of the accidents in HSR operations have involved obstructions on the ROW, with vehicular grade crossings topping the list. The remaining incidents most often involved equipment malfunctions attributed to flaws in the engineering and/or construction phases of rolling stock or infrastructure. Over time, the HSR industry has introduced and/or refined a wide array of safety features that have significantly reduced the number of injuries and fatalities and the amount of damage, particularly in comparison with other passenger train operations such as densely crowded commuter trains.

The design of an HSR trainset's between-car connections plays the most significant role in the severity of an incident. The more a train, by design, stays linear and upright in a collision or derailment, the better the life-safety conditions. Steps to address crashworthiness have also improved safety. In the United States, all revenue equipment must be built to comply with Federal Railroad Administration (FRA) crashworthiness standards, which are typically much more stringent than those in other countries.

Reducing the number of grade-crossings or completely eliminating them is the most significant step HSR operators can take to reduce collision hazards. The potential for vehicles, equipment, pedestrians and livestock to venture on to the ROW, outside of public crossings, must also be addressed. Advancements in isolating HSR ROW and installing systems to prevent and/or detect accidental or intentional intrusion not only reduce accidents but also enhance security measures, particularly in areas of critical vulnerability.

The HSR safety record in Europe and Asia clearly reveals that high numbers of injuries and deaths occur when HSR trains collide with other trains or massive objects and that specific locations or design features of the infrastructure put rail passengers at greater risk of catastrophic consequences should an incident occur. However, these vulnerabilities are not unique to HSR. Intercity, commuter, and heavy rail all operate in the same or similar environments. Formulating a strategy for securing HSR in the United States, separate and apart from the rest of the passenger and even freight rail network, is not warranted solely because of the greater speed of HSR trains.

INTRODUCTION

As part of the Mineta Transportation Institute's (MTI's) continuing research effort on high-speed rail (HSR) security and safety, this report presents an analysis of information relating to attacks, attempted attacks, and plots against HSR systems.

While terrorist attacks aimed at trains and buses have increased over the past several decades, very few attacks have targeted HSR. To gain possible insights into the consequences of successful terrorist attacks, this inquiry includes accidents and other incidents that have resulted in injuries, fatalities, or extensive asset damage on HSR. The consequences of major accidents might also affect terrorists' perceptions and decisionmaking.

The authors reviewed security at selected HSR systems in Europe and Japan to identify measures that could be applied to HSR systems currently under development in the United States.

These three lines of inquiry—data from accidents, terrorist attacks, and existing security measures—are used in this report to develop an overall strategy for HSR security.

Objective of the Research

The objective of the research is not to dictate security regimes, but to:

- Distill lessons from the history of accidents and terrorist attacks
- Review security measures at existing HSR systems
- Explore security-regime options
- Suggest principles for an overall security strategy

An Empirical Approach

The approach is empirical. The authors analyzed data on all attacks against HSR targets recorded in the MTI Database of Terrorist and Serious Criminal Attacks Against Public Surface Transportation, beginning in 1970. They also analyzed HSR accident data to identify patterns in event types and outcomes, particularly lethality and injuries, damage, and service disruption. They sought to ascertain which events produced outcomes that would be attractive to a potential attacker and that terrorists might attempt to create or initiate.

The accident analysis focused on incidents since 1966 that occurred in the United States, Asia, and Europe. Since that year, HSR systems have expanded rapidly, especially in Europe, which currently hosts HSR operations that are well established and analogous to U.S. operations.

What is High-Speed Rail?

High-speed rail is a malleable term. For the purpose of this inquiry, it comprises systems with the following characteristics:

- Trains designed for sustained operation at or above 200 kph (125 mph)
- Trains that provide service between population centers or urbanized areas, with limited interim stops
- Trains that typically use semi-permanently connected sets of power cars, locomotives, and coaches of various configurations
- Rights-of-way (ROWs) that are grade-separated; that have limited, if any, level crossings with roads or other railroads; and that have access barriers
- Trains that have dedicated-use ROWs, particularly outside of terminals
- Trains that most often use overhead, constantly tensioned catenary to supply power to locomotives and power cars
- Systems that use some type of automatic train control (ATC) or positive train control (PTC) with line-side and cab signals

Criteria for Incidents Analyzed

Accidents, attacks, attempted attacks, and plots that involved HSR operations or equipment (either moving or stationary in a train station or in a storage or service yard) were defined as HSR incidents, attacks, or attempted attacks.

Accidents, attacks, or threats involving tracks or ROWs used exclusively by HSR trains were deemed HSR events.

Attacks or attempted attacks against ROWs that host HSR service along with other passenger and/or freight rail equipment/operations, unless their true intent or target choice was specifically identified as a non-HSR asset, were also classified as HSR events.

Organization of the Report

The report has three chapters. Chapter I discusses security measures abroad and offers security principles. Chapter II reviews terrorist attacks on HSR and their implications for security. Chapter III reviews HSR accidents and their implications for HSR security. In addition, Appendix A provides details of HSR incidents in Europe, Asia, and the United States. Finally, Appendix B discusses current best security practices.

I. SECURITY PRINCIPLES AND MEASURES

Almost any discussion of security causes many HSR proponents to bristle. They worry not only that mere mention of the issue will invite proposals for security regimes or heavy-handed government edicts that will interfere with fast, convenient rail travel but that even talking about terrorist threats might somehow undermine campaigns to win support for new HSR systems. In their view, no one who writes about security can be trusted to do anything but cause trouble.

In fact, however, the subject of security need not create adversaries, and the right time to initiate a discussion is *now*, as new HSR systems are being designed and built. This report is intended to inform that discussion by addressing the following questions:

1. Does HSR merit more security or different security measures than other passenger rail?
2. Is it appropriate to consider reducing security for passenger rail?
3. What threats drive security concerns?
4. What can be learned from HSR security in Europe and Japan?
5. What can be learned from terrorist attacks on HSR?
6. What can be learned from accidents involving HSR?
7. Should HSR passengers go through security screening?
8. Would increased security for HSR provide a net security benefit to public surface transportation?
9. Where should HSR security efforts be focused?
10. What are the principles of an HSR security strategy?

1. Does HSR Merit More Security or Different Security Measures than Other Passenger Rail?

HSR creates opportunities to improve security. The history of rail security measures is similar to that of airport security. Most airports were designed and built before airline security became a major consideration. The system at airports today is the accumulation of four decades of security measures. Likewise, most railway stations were built decades before security became a major concern and had to be modified and retrofitted for security. For example, blast-resistant trash containers and lockers have been installed, bollards have been deployed, and structural changes have been made to prevent or reduce the effects of large vehicle bombs. HSR expansion in the United States will bring about the construction

of new stations, ROWs, and rolling stock and therefore represents an opportunity to design and build in security at the beginning.

The fundamental question is, *Does HSR merit more security or different security measures than those in place for non-HSR?* Some argue that HSR merits more security, for a number of reasons:

- HSR is an iconic target, making it more attractive to terrorists than non-HSR.
- HSR is faster, so derailed high-speed trains would result in more casualties.
- HSR typically serves a customer base comprising the country's government and business leaders.
- The construction of HSR systems could provoke opposition from some members of local communities who might be tempted to take disruptive action.

Is HSR iconic? Visually and symbolically, HSR trains are much like the streamliners and famous named passenger trains of the 1930s and 1940s. In Europe and Asia, HSR is seen as iconic of both national identity and economic status—a symbol of technological achievement and national progress. But new Metro lines, such as those in Washington, Atlanta, Barcelona, and London (the Heathrow Express), are also modern in looks and have an iconic quality. Furthermore, old stations, including New York's Grand Central and Penn Stations, London's Victoria Station, and Melbourne's Flinders Street Station, as well as new ones like France's Avignon Station, also have iconic value. As high-speed trains become more common and operate simply as faster commuter trains, their iconic premium will diminish.

HSR trains do go faster, but does higher velocity lead to greater casualties? Accident data from HSR offer a mixed picture—derailments can be disastrous, but the average number of casualties in the data is driven by just two incidents, one in Germany and one in China. And the majority of casualties in these incidents resulted from the design of the infrastructure. In Germany, the derailing train knocked out the supports for an overpass, and the falling concrete crushed train cars. In China, derailing cars fell 50 feet from a viaduct. Other HSR derailments suggest that the rigid coupling of HSR trains impedes rolling over or jackknifing, two major causes of derailment casualties. In the realm of terrorism, one incident in Russia drives perceptions. In November 2009, saboteurs detonated an explosive charge under the Nevsky Express that was powerful enough to blow one of the coaches into the air. Twenty-seven persons were killed, and 95 were injured.

The fact that the Nevsky Express was popular with Russian politicians and businessmen may have contributed to its being selected as a target. In addition to the November 2009 attack, it was bombed in August 2007, with 60 people being injured. HSR trains often do carry an elite passenger load. Similarly, high-end hotels are selected as targets by terrorists for both their iconic value and the fact that they are gathering places for visiting and local elite. Again, however, this feature will diminish as HSR becomes more common and serves growing numbers of long-distance commuters.

HSR construction projects may arouse new adversaries. Some HSR systems will face local opposition from those who may see fenced ROWs or roadbeds resting on multistory berms to create easy underpasses for vehicular traffic as threats to their local community. In Europe, anarchists and malicious pranksters have disrupted HSR. A few extremists could carry out acts of sabotage during the HSR construction phase or subsequent operations.

These actions are likely to take the form of vandalism or low-level sabotage aimed at causing delay and disruption rather than death and destruction. Historical examples include objects placed on rails, grappling hooks that tear down catenary wires, and sabotage of power lines to the system. The security approach in the case of such incidents must be rapid response and restoration.

It can also be argued that HSR has characteristics that make it *less* attractive to terrorists. Passenger loads on HSR trains, per car and per train, are typically less than those on slower-speed commuter or intercity trains, reducing the chances of replicating the high body counts achieved in the worst terrorist attacks on such systems.

Reservations and advance ticket sales for HSR travel create opportunities for identity checks. Unlike regional or commuter rail, HSR usually has all-reserved seating, which requires making an advanced booking. However, this practice may not be followed where HSR serves as commuter rail.

Exclusive HSR ROWs, often fenced, reduce the vulnerability of the tracks to unauthorized intentional access and increase the chances of detection of sabotage. (Exclusive ROWs, however, also may reduce train frequency, increasing exposure to sabotage.)

Hard roadbed and seamless rail construction make rail sabotage harder to conceal. Attacks on the French TGV in 1995 and two attacks on the Nevsky Express suggest that the high speed of the trains makes sabotage more difficult but not impossible.

2. Is it Appropriate to Consider Reducing Security for Passenger Rail?

This seems like a radical question, but if the expansion of HSR offers an opportunity to examine security enhancements, it should also be an occasion to have a sensible discussion about risk to all rail passengers—HSR and non-HSR. Security should not become a ratchet where the current level becomes the norm and can only be increased.

Most security measures are aimed at deterring or preventing ordinary crime—pickpocketing, drunk or unruly passengers, armed assaults or robberies in stations or on board trains, people being pushed onto the tracks from platforms, suicides, turnstile-jumping, vandalism and other forms of property destruction, routine bomb threats. These measures will continue. Anticrime measures such as the visible presence of security personnel, closed-circuit television (CCTV) coverage, suspicious-activity reporting, and stations designed to eliminate dim corners and narrow passageways where crimes may occur may also have some deterrent effect on terrorists.

Our focus here is on measures specifically intended to deter, detect, or prevent acts of terrorism—bombings, armed assault, arson, and attempts to derail trains or disrupt traffic. Antiterrorism security measures include the presence of more-heavily armed security personnel, explosives-detection canines, monitoring or detection systems for chemical or radiological materials, identity checks, passenger screening, and luggage inspection. These measures are associated with air travel, causing some to fear the imposition of aviation-style security on surface transportation, or at least high-speed trains. This last issue is discussed in detail under Question 7 below.

In the past 40 years, only one person in the United States died as a consequence of a terrorist attack on a rail target—the 1995 derailment of the Sunset Limited. Nevertheless, the long-term increase in the number and lethality of terrorist attacks on trains and buses worldwide argues for continued antiterrorism security measures. Between 9/11 and December 31, 2012, 2,190 terrorist or serious criminal attacks were made against public surface transportation, resulting in 4,304 fatalities. Of these attacks, 870 were against rail targets, resulting in 1,362 fatalities.

In addition to those attacks, 15 terrorist plots that we know about against rail passengers either failed or were foiled by authorities. While most of these plots were interrupted in their early planning stages, they were intended to kill in quantity.

Just before his death, Osama bin Laden was urging followers to carry out attacks on rail targets in the United States. He envisioned derailing speeding passenger trains. U.S. authorities uncovered five terrorist plots against rail targets, all of which were directed against passengers on subways or commuter trains. After devastating terrorist attacks on trains in Madrid in 2004, where 191 persons died, and London in 2005, where 52 persons died, and at least eight failed or foiled terrorist plots directed against rail since 9/11, Europe has increased the presence of armed security personnel and CCTV coverage.

Just as it is hard to make the case that HSR requires more security than non-HSR, it is difficult to argue that HSR requires less security. An argument can be made that some of the security measures currently in place for all passenger rail are unnecessary, but that is an argument about rail security in general, not about the differences between HSR and non-HSR.

These circumstances make it difficult to argue for adopting a level of security for HSR that is lower than that for non-HSR or for lowering the overall level of security for all passenger rail systems. That does not prelude appropriate future reductions.

3. What Threats Drive Security Concerns?

Security for passenger rail is driven by both actual and anticipated events. Several scenarios cause concern:

- Improvised explosive devices (IEDs) detonated on board trains or at stations. The Madrid and London attacks and the 2006 bombing of a Mumbai commuter train,

which killed 207 people, are examples. Several of the terrorist plots interrupted in the United States envisioned the use of IEDs.

- An active shooter or multiple shooters on board a train or at stations. In 1993, six people were killed by a deranged gunman on board a Long Island commuter train, and in 2008, two terrorists opened fire on passengers at Mumbai's Central Rail Terminal, killing 56 people.

- Attempts to derail trains by sabotaging the tracks with IEDs, using mechanical means, or placing obstacles on the tracks. This is what Osama bin Laden had in mind. The worst such case was the 2009 derailment of the Nevsky Express, in which 27 people died.

- Disruption of traffic by attacking cables or signaling systems, bomb threats, or other means.

4. What Can Be Learned from HSR Security in Europe and Japan?

There are no international or regional standards of security for rail systems, either HSR or non-HSR. National operators of HSR systems impose their own security measures. The European Union (EU) sees a need for harmonization of security practices but is not close to regulation. The approach is likely to remain one of best practices selected by authorities and operators to meet local needs.

Industry organizations such as the International Union of Public Transport (UIPT) and the International Union of Railways (UIC) are in the process of reviewing security for passenger rail, but they are not likely to issue standards. The UITP is cataloging best practices for all passenger rail systems.

HSR Security in Europe

Special security measures are in effect for the Eurostar, the high-speed trains that run between London and Paris and Brussels. These measures preceded 9/11 and initially reflected concerns about the terrorist campaign being conducted by the Irish Republican Army (IRA), which was active in the United Kingdom (UK) during the construction of the tunnel under the English Channel.

While security of the train and tunnel were priority concerns, preventing illegal immigration to the UK is also an important concern, and the Eurostar crosses the France-UK border. The UK is not a member of the Schengen Agreement, which allows free circulation across borders within the Schengen space, and is determined to prevent illegal immigration from countries on the continent.

The French terminal for the Eurostar, the Gare du Nord, has dedicated platforms for it. These are separated from the station's other platforms by glass walls and high metallic fences. Eurostar passengers enter through a special entrance inside the station, where luggage is x-rayed and passengers are screened. The screening is much like pre-9/11

airport security: Passengers do not have to remove their shoes, may carry unlimited quantities of liquids and gels, and do not pass through body scanners.

Passport control and customs inspections, both French and British, are completed at the boarding station so that upon arrival, passengers merely disembark. It is recommended that passengers arrive at the station 45 minutes before scheduled departure to complete these procedures.

Similar measures are in effect at the Gare du Midi in Brussels, the other Eurostar terminus on the continent, and at St. Pancras Station in London, the British terminus. Tickets can be purchased at these stations before departure, but this does not guarantee a reserved seat on the train desired. That requires advance booking.

The Eurostar is unique in that it is the only HSR train in Europe to have special security measures. All other high-speed trains are treated the same as other passenger trains—there is no passenger or luggage screening or other security checks, even for cross-border trains, although random ticket or ID checks can occur on board some trains. Countries within the Schengen space operate on the principle of free circulation and reflect the general attitude that without new technologies that currently do not exist, any form of passenger screening would onerously delay travel times and, given current threat assessments, are unwarranted.

The emphasis in European HSR is on convenience. In France, passengers on HSR (TGV) trains have to check in only two minutes before departure. On other trains, passengers merely need to be on board before the doors close.

Some HSR trains in Spain have security measures. Passengers on long-distance high-speed trains must have their ID confirmed, and their baggage is scanned. Selected passengers may be subjected to a personal search. Spain also has ticket controls at the platform entrance. Still, passengers may arrive only minutes before departure without fear of missing the train. Both armed police and private security guards patrol regional and commuter trains in Spain.

German authorities have not mandated passenger or luggage screening for HSR trains. Germany has no dedicated high-speed corridors or platforms, so HSR is fully integrated into the national rail system, making it virtually impossible to separate HSR from non-HSR passengers. German authorities also point out that the high-volume metro systems, not the longer-distance trains, cause the greatest security concern. Germany relies primarily on surveillance, utilizing both uniformed guards and CCTV at train stations.

Following the terrorist bomb attacks on London's tube in 2005, officials at the British Department of Transport carried out trials to test the feasibility of mass passenger screening. They found that while riders were generally positive about the need for security, they were unwilling to accept major delays or the loss of privacy that came with screening. Despite the continuing high terrorist threat level, the Department of Transport concluded in 2008 that airport-style screening of all rail and underground passengers was not possible with the technology then available.

In 2012, Britain's Home Office initiated a search for new and emerging technologies capable of rapidly screening large numbers of passengers. If such technologies were available, they could be deployed at major train and tube stations, with no special regime for HSR trains other than the existing measures in place to protect the Eurostar. The technology would be used to detect explosives, guns, and knives being carried by passengers themselves or in their bags. However, the Home Office indicated that the screening must be achieved without imposing any delay. Technologies to detect chemical and biological substances are also being sought.

New stations such as the station in Avignon, France, and the stations along the new Meteor Metro line in Paris, are designed to facilitate surveillance. They have open spaces, have no dim corners, and are well lit. European countries—in particular, the UK, France, and Germany—make extensive use of CCTV. Armed police are deployed at train and subway stations and on the trains.

As for track security, HSR ROWs are fenced along their entire length. Level crossings are not permitted. Bridges over the lines have sensors to detect objects that fall or that may be thrown onto the tracks. In the 1990s in France, early-morning sweeper trains were dispatched before passenger traffic began.

HSR Security in Japan

There are no screening procedures for passengers boarding high-speed or other trains in Japan. After the 1995 sarin attacks on Tokyo's subways, CCTV surveillance was increased and surveillance cameras were installed on board trains to keep passengers "feeling secure."

Summary

There are no international standards for HSR trains, although common standards for rail security are being discussed in the EU. With the exception of the Eurostar and longer-distance trains in Spain, there are no separate security regimes for HSR trains in the European countries reviewed for this study or in Japan. HSR trains are generally integrated with non-HSR trains, precluding separate security regimes.

Screening passengers and luggage, even on a random basis, as practiced on some rail systems in the United States, has been rejected in Europe, despite the attacks in Madrid and London and other terrorist plots that have been uncovered. There is no passenger screening in Japan.

The absence of security delays is viewed as a major attraction of rail travel. European authorities see the greatest vulnerability in the crowded metro and subway stations and trains. Despite a higher terrorist threat level, European attitudes about the degree to which risk can be reduced differ from those of Americans. Instead of passenger screening, European rail systems rely on the presence of armed guards and extensive CCTV surveillance. Greater attention is given to designing security into new stations than to passenger screening.

5. What Can Be Learned from Terrorist Attacks on HSR?

According to the MTI Database of Attacks on Surface Transportation, through 2012, 33 terrorist attacks had been made on HSR targets, which include HSR trains and the tracks and other infrastructure they use, all but one in Europe.

Although European countries have suffered terrorist campaigns, including deadly attacks on passenger rail targets, for the most part, terrorism in Europe has not matched the volume or high lethality of terrorist attacks in India, Pakistan, or Israel. The exception is Russia, where terrorist attacks have resulted in large numbers of fatalities; a total of 32 persons in Russia have been killed in terrorist attacks on HSR.

Twenty-four of the 33 attacks (72.7%) involved bombs, but only three of the 29 IEDs, other bombs, or improvised incendiary devices (IIDs)[1] used in these 24 attacks were carried on board and placed in passenger compartments. One of these resulted in five fatalities. Twenty-two (75.9%) of the bombs were placed on a track, a bridge, or near a tunnel. One of them, a 7- to 8-kg (15- to 18-lb) charge, caused the derailment of the Nevsky Express. None of the other attacks resulted in fatalities.

There are some interesting differences between terrorist attacks on HSR and those on non-HSR targets. The non-HSR targets in this analysis included passenger trains (subway trains, intercity or commuter trains, etc.), train stations, tracks, and other infrastructure to ensure an accurate comparison with HSR attacks.[2]

The percentage of non-HSR attacks involving bombs is higher than that of HSR attacks, but the percentage of fatalities caused by bombs is lower. A total of 1,283 attacks against non-HSR targets killed 3,277 people. Of these attacks, 1,090 (85%) involved a total of 1,510 bombs (compared with 72.7% for HSR targets). Attacks involving bombs killed 2,495 people, or 76.1% of the total. By comparison, *all* of the fatalities in HSR attacks were caused by bombs.

We compared the largest category of bomb attacks placed in the passenger compartment recorded in the MTI database ("Concealed or Placed in Passenger Compartment, Unspecified," which we refer to as *passenger-compartment bombs*), with the placement of bombs in or on railway tracks, tunnels, or bridges (which we refer to as *track bombs*).

The percentage of track bombs in non-HSR attacks was 58.9% (890 out of 1,510 devices); in HSR attacks, the percentage was much higher, 75.9% (22 out of 29 devices). By comparison, the percentage of passenger-compartment bombs was roughly the same: 11.5% (173 out of 1,510 devices) for non-HSR attacks and 10.3% (3 out of 29 devices) for HSR attacks.

Track bombs designed to cause derailments were far more frequent and far more lethal in HSR attacks than in non-HSR attacks. Eight (33.3%) of the 24 bomb attacks against HSR targets were designed to cause derailments, and they resulted in 27 (84.4%) of the

[1] In this report, the term bomb refers collectively to IEDs, IIDs, mines, dynamite, and other explosives.

[2] While attacks have been made against the outside and inside areas of non-HSR stations, there have been none—so far —against stations in HSR transportation.

32 fatalities. By comparison, only 97 (8.9%) of the 1,090 bomb attacks against non-HSR targets were designed to cause derailments, and they caused only 475 (19.0%) of the 2,495 fatalities.

Finally, there are considerable differences between the numbers and lethality of track bombs and passenger-compartment bombs for HSR and non-HSR targets. The numbers of fatalities per device (FPD) are shown in Table 1.

Table 1. Fatalities Per Device in HSR and Non-HSR Bomb Attacks

Category	All HSR Attacks	All Non-HSR Attacks
All Bomb Attacks		
Total # of Devices in Bomb Attacks	29	1,510
Overal Fatalities Per Device (FPD)	1.1 FPD	1.7 FPD
Bombs on Tracks		
# of Track Bombs (% of All HSR or Non-HSR Bombs)	22 (75.9%)	890 (58.9%)
FPD of All HSR/Non-HSR Track Bombs	1.2 FPD	0.9 FPD
Greater/Less than Overall FPD	0.1 FPD higher (9.1%)	0.8 FPD lower (47.1%)
Bombs in Passenger Compartment		
#/% of All Passenger Compartment Bombs	3 (10.3%)	173 (11.5%)
FPD of All Passenger Compartment Bombs	1.7 FPD	4.5 FPD
Greater/Less than Overall FPD	0.6 FPD higher (54.5%)	2.8 FPD higher (164.7% higher)

The average FPD is higher for non-HSR targets (1.7) than for HSR targets (1.1). Despite that, the FPD of track bombs used against HSR targets is actually higher (1.2) than that of track bombs used against non-HSR targets (0.9) and is higher for HSR targets (9.1%) than the overall average; for non-HSR targets, it is 47.1% lower.

The situation for passenger-compartment bombs is reversed, and dramatically. The average FPD for these bombs against HSR targets is 1.7, whereas against non-HSR targets, it is 4.5. The FPD for passenger-compartment bombs was 54.5% higher than the overall average for HSR attacks, but the comparable increase for non-HSR attacks was 164.7%.

The overall lethality rate of terrorist attacks on HSR targets, measured in fatalities per attack and FPD, is significantly lower than that for attacks on non-HSR targets. There were only 1.0 fatalities per attack on HSR targets, including the deadly derailment in Russia, and only 0.15 fatalities per attack, excluding the Russian derailment; the comparable FPD values are 1.1 and 0.17. For non-HSR targets, there were 2.6 fatalities per attack and 1.7 FPD.

These poor results, from the terrorists' perspective, suggest that HSR is not likely to be the primary target of terrorists seeking high body counts. Terrorists bent upon slaughter can more easily achieve their goal by attacking crowded subways and commuter trains, as they have done, although they could try to benefit from the iconic value of HSR by detonating bombs in HSR stations or on HSR platforms. (In some cases, densely packed

passengers may absorb some of the effects of a bomb blast, reducing the total number of casualties.)

The results of a successful derailment of an HSR train could theoretically match those of a successful bombing of a crowded commuter train, but as indicated previously, because of the rigid coupling of HSR trainsets, high-casualty HSR derailments are rare. Only two accidental HSR derailments and one derailment caused by terrorists have resulted in casualties of that magnitude. Only three of 11 attempted terrorist derailments of HSR trains succeeded. This suggests that security measures should focus on tracks and stations. And, as shown above, track bombs used against HSR targets are more lethal in absolute and relative terms than those used against non-HSR targets, and derailment attempts against HSR trains have so far been far more lethal than those against non-HSR trains.

Officials charged with security should not focus exclusively on Madrid and Nevsky Express spectaculars and ignore lower-level threats. The latter are more likely to come from anarchists, local opponents of HSR construction, even pranksters, whose actions are likely to be aimed not at causing casualties but at blocking HSR projects and disrupting operations. IEDs or fake IEDs, IIDs, and arson attempts and threats may support extortion attempts.

The most likely targets are tracks and supporting infrastructure (electrical supply, overhead wires, and obstacles on tracks). Prevention is difficult. Rail systems will need contingency planning and resiliency leading to rapid restoration of service.

6. What Can Be Learned from Accidents Involving HSR?

Because of the fortunate paucity of attacks on HSR systems, our research was broadened to include data from accidents involving HSR, which could provide additional information about the possible consequences of potential future terrorist attacks and might also offer insights into such attacks. Might terrorists, for example, try to exploit vulnerabilities revealed by HSR accidents in an attempt to replicate them? This inquiry was not intended to result in conclusions about safety itself. Nevertheless, some conclusions emerged.

We examined available accident data for HSR systems in 12 countries. Those data may not be complete, but they capture the major incidents.

We identified a total of 73 accidents, which resulted in 167 fatalities. While any death is tragic, these numbers indicate that HSR is safe. There has been, on average, one accident in every three operating years in the 12 countries and one fatal accident every 13 years—less than one fatality per operating year.

Seventeen of the 73 accidents resulted in fatalities. These include three suicides and seven motorists or automobile passengers struck at grade crossings. (Data on pedestrians killed on the tracks were unavailable.) In addition, there was one case of a passenger falling or jumping from a train.

The overall average is 2.4 fatalities per accident; the median is less than 1. And 101 of the 167 fatalities occurred in a single accident in Germany, when a faulty wheel on a high-speed train led to a disastrous derailment that hurled coaches into an abutment.

The most common accidents were collisions with vehicles at grade crossings—nine incidents, two of which resulted in train derailments and a total of nine fatalities (seven in the vehicles).

The most lethal events, on average, were the derailments. Of seven derailments, two were disasters. The one in Germany and one in China that resulted in 40 fatalities account for 91% of the fatalities. These two events, however, added to the two HSR derailments caused by terrorists in Russia, one of which killed 27 people and injured 95 and the other of which injured 60 people, may lead to terrorist perceptions that one way to achieve high body counts is by derailing high-speed trains. This is what Osama bin Laden may have had in mind when he urged followers to derail passenger trains in the United States.

7. Should HSR Passengers Go Through Security Screening?

Passenger screening is the most controversial aspect of security. Should all HSR passengers undergo screening like that of passengers boarding the Eurostar, or should they board as other rail passengers do now?

There are a number of options for HSR security screening.

1. An aviation-security model that involves the rigorous screening of all HSR passengers and their carry-on baggage for weapons and explosives.

2. An option that might be called “aviation security lite,” such as a Eurostar equivalent. In such a model, 100% of HSR passengers would be screened but would undergo a less-rigorous inspection. They would pass through a metal detector, and carry-on luggage would be x-rayed, but they would not have to remove shoes, belts, or jackets—roughly the equivalent of the Transportation Security Administration’s (TSA’s) PreCheck regime, recently introduced at some U.S. airports, where trusted travelers are permitted to pass through a lighter security inspection. (It should be noted that since the amount of explosives that can cause a catastrophic loss of a train is significantly greater than the amount that can bring down an airliner, satisfactory detection rates could be achieved with far greater throughput.)

3. Subjecting HSR passengers to the same measures as those currently used for some non-HSR passengers. These include ID checks, explosives-detecting canines, and, most important, “selective” passenger screening in which passengers are randomly selected for voluntary screening, giving authorities using uniformed and undercover officers the chance to observe passengers who attempt to avoid screening rather than just objecting to it.

4. A purely theoretical but unlikely fourth option: The expansion of HSR systems in the United States could be the occasion for a fundamental reassessment of

risk, leading to an overall reduction in all passenger rail security—for example, by eliminating any attempts at passenger screening.

Screening 100% of passengers seems unnecessary, impractical, and inadvisable. Imposing an aviation-security model on HSR passengers would be difficult and is unnecessary. Any passenger-screening model must start with what needs to be prevented.

Very small quantities of explosives that can cause catastrophic airliner crashes if smuggled on board cannot derail a train or cause catastrophic train crashes. Passenger screening for rail would involve looking for significantly larger quantities, thus facilitating the search. (The exact quantities are still a topic of research.)

The same is true of firearms and other weapons. One can theoretically hijack a train but cannot crash it into the side of a skyscraper. (TSA has recently relaxed its restrictions on small knives and certain other objects.) Weapons pose a danger to passengers on board, but no more of a threat than that to persons at any other public venue. Rail systems now prohibit passengers from carrying certain items on board, including weapons. (It is not certain how these rules apply in states in the United States where carrying concealed weapons is authorized.)

Adopting 100% screening would have implications not only for passengers and screeners but also for station design and construction, location of vendors at stations, even train schedules.

Screening must be carried out not only at a train's initial departure point but also at every stop along the entire route. This would require all boarding passengers to pass through checkpoints single file at some point. It also would require the physical isolation of HSR passengers from unscreened, non-HSR passengers—a separate platform for HSR boarding would have to remain a sterile area. Station design would have to provide for this.

Since stops at stations along routes are brief, passengers would have to be screened in advance and held in a secure area, then allowed to board quickly, or stop times would have to be lengthened—last-minute boarding would become impractical.

All other entrants to the secure area would also have to be screened, and any security breeches would have to be resolved before boarding is permitted. In a rail system, this could cause delays along the entire route. In the case of a security breach, either the train would have to leave the affected station without boarding passengers, leaving them to find space on the next train, or the entire system would come to a halt.

Maintaining a separate security regime for HSR passengers would impede its integration with other rail systems and transportation modes as well as the development of HSR trains as commuter rail. Conversely, the smooth integration of HSR with regional, commuter, and rail transit services in large terminals would make it more difficult to impose a separate security regime for HSR passengers. Instead of treating HSR passengers as a special category for security, it may be preferable to look at the security of the entire station.

Security screening theoretically may be practical for longer-distance, point-to-point travel with no or very few intermediate stops (e.g., London to Paris on the Eurostar), but it would be difficult to impose on high-speed commuter trains with multiple stops (such as the U.S. Acela trains).

Imposing a robust passenger-screening regime would also undermine one of the major attractions of HSR, its convenience:

- Trains run from city center to city center. There are no lengthy commutes to and from airports.
- Passengers can easily bring their luggage on board.
- There are no security delays. Passengers can arrive at a train station closer to departure time.
- There are no or few onerous security measures (e.g., no passenger screening). Passengers can keep their shoes and jackets on—a contentious issue in the United States.
- Roomier coaches provide the ability to walk around.
- HSR trains can provide convenient connections with other modes of surface transportation, including local trains and subways, without changing stations.

8. Would Increased Security for HSR Offer a Net Security Benefit to Public Surface Transportation?

Terrorists always have an advantage. Unlike armies, they do not have to attack specific targets of military value within a limited time frame. Unlike ordinary criminals, they do not have to go where the money is. Terrorists can attack anything, anywhere, any time.

With finite resources, governments cannot protect everything, everywhere, all the time. Authorities are obliged to make decisions about the allocation of security resources. Generally, such decisions take into account the threat—the capabilities, intentions, and past actions of the likely terrorist adversaries; vulnerability—the targets that fall within the range of the terrorists' capabilities; and consequences—what could happen if a terrorist attack is successful.

One additional criterion is whether providing security for a specific target or category of targets offers a *net security benefit,* that is, does it prevent terrorists from doing something that they cannot do elsewhere with equal ease and consequences?

It is especially difficult to obtain a net security benefit by protecting public places—shopping malls, tourist sites, or crowded public squares, for example. Protecting public places is difficult and costly. If the security measures have no effect other than obliging terrorists to

select other public spaces where they can expect to achieve the same results, there is no net security benefit.

Security works in that terrorists generally avoid well-defended targets. Security, however, does not prevent determined terrorists from carrying out an attack. It more often merely displaces the planned attack to a less-protected target.

This is another fundamental difference between terrorism and ordinary crime. Pickpocketing, robberies, assaults, vandalism, and disorderly behavior are ordinary crimes that occur at transportation hubs and on board trains. Perpetrators are numerous, but they have little determination. Ordinary crimes can be reduced through environmental design. Terrorists are comparatively rare, but they are more determined. Committed to action, they are not so easily deterred. Denied one target, they will often find another.

For potential targets where the consequences of a successful attack could be catastrophic, it is worthwhile to push terrorists to softer targets where the consequences are likely to be less. The reduction in potential consequences provides a net security benefit.

Aviation security and public surface transportation security illustrate the point. Terrorists remain obsessed with attacking airliners, where successful sabotage can cause hundreds of fatalities, while successful hijackings, as the 9/11 attacks demonstrated, can result in thousands of deaths and hundreds of billions of dollars in destruction and the resulting loss of business. Therefore, keeping explosives and other weapons off aircraft offers a net security benefit.

Terrorists also attack trains and buses, but the number of fatalities in the bloodiest attacks has been around 200 (191 in the 2004 Madrid attack and 207 in the 2006 Mumbai attack)—clearly lower than the numbers in the worst attacks on aviation. The same differences show up when the average or median numbers of casualties are compared.

This is not to say that terrorists, unable to blow up airplanes, blow up trains instead. There is not a direct tradeoff. Unable to get at airliners, terrorists have sometimes attacked airports. Buses and trains have become killing fields, reflecting terrorists' determination to kill in quantity and willingness to kill indiscriminately. If body count is the terrorists' paramount objective, trains and buses make excellent targets. They are easily accessible public places offering crowds of people in confined spaces.

Unlike the situation in aviation, keeping weapons and bombs off HSR trains may do little more than shift terrorist sights to ordinary trains and subways, which are already well-established terrorist targets, or still other easily accessible targets outside of the transportation sector. That may be good news for HSR passengers, but it offers virtually no net security benefit to transportation users or society. Tighter security for HSR, if it only displaces risk to non-HSR, provides no net security benefit.

History, ownership, jurisdictions, and politics cause us to compartmentalize targets, seeing them as isolated entities. Some compartmentalization is necessary—it is difficult to evaluate tradeoffs between increasing rail security and reducing infant deaths or buying a

new Navy warship. But viewing passenger rail transportation as a security domain makes sense. There is less certainty about treating HSR as a separate domain within it.

9. Where Should HSR Security Efforts Be Focused?

The historical record of attacks against HSR targets is sparse; some of the 33 attacks were related to a single campaign aimed at disruption—not enough for confident statistical analysis. Nonetheless, the data that do exist do not support the hypothesis that HSR passengers are in greater danger from bombs smuggled on board high-speed trains than other passengers. Indeed, the record suggests that HSR may be less of a target. Given the difficulty of maintaining a separate security regime for HSR passengers (to say nothing about sustaining the moral argument of treating HSR passengers as a special class), it may make more sense to treat all rail passengers as a single class, allocating security resources according to threat, not target category. This would mean putting the focus on the station rather than the train.

Focusing on the station would match current security theory in Europe and Japan, where HSR has become merely another component of an integrated passenger rail system. Stations are designed to discourage ordinary crime; to provide some level of deterrence to terrorists by facilitating surveillance and domain awareness; and to mitigate the consequences of terrorist bombings by eliminating or strengthening places where bombs could be easily hidden, such as lockers and trash bins, and by creating large open spaces where blast effects would be more easily vented. Stations in newer systems, including Washington DC's Metro and the Meteor line in Paris, reflect some of these new design features.

Stations are also where regimes of selective passenger screening could be implemented and directed at HSR passengers as well as non-HSR passengers. Selective screening is one of the options mentioned above. Random passenger screening can be expanded to screen more passengers and can be easily reduced in accordance with the threat; the specific search protocols can also be adjusted.

If there is an area where HSR merits special attention, it is along the ROW. This is where terrorists have focused most of their action, planting bombs or using mechanical means to cause derailments or to simply disrupt traffic. Only through derailments can terrorists hope to achieve the high body counts that have become a hallmark of contemporary terrorism. At the other end of the spectrum, disruption of HSR traffic by planting fake devices or simply placing obstacles has become a mode of protest.

Surveillance along long lines is always a challenge. Tamper-detection systems are part of the rails themselves. Sweeper trains or their miniature equivalents can precede HSR traffic to ensure that the line is safe. Even small drones could be programmed to provide aerial surveillance of tracks and power lines.

10. What are the Principles of an HSR Security Strategy?

- Our analysis of accidents and terrorist attacks indicates that HSR travel is very safe. The most frequent sources of casualties are pedestrians on the tracks and accidents at grade crossings. These can be reduced. Terrorists have attacked HSR targets, but not with the frequency or lethality of their attacks on subways and commuter trains.

- The construction of new HSR systems should be viewed as an opportunity to review rail security for all connecting rail transportation systems—the goal is passenger security, not just HSR passenger security. Appendix B describes current best security practices.

- Preventing attacks is difficult, but it is not the only goal of security. Facilitating emergency response and rapid restoration of service should also be considered security goals.

- A review of failed and foiled terrorist plots suggests that intelligence efforts have been critical in stopping terrorist plots, but intelligence efforts alone clearly cannot foil every terrorist attempt. Physical security measures offer some deterrent value and can undeniably stop some of the less-competent attackers. They also complicate planning for the higher-end terrorists, which, in turn, may increase their exposure to intelligence efforts.

- Since HSR will be connected to non-HSR systems, and in many systems is envisioned to function as high-speed commuter transit, separate, more-stringent security regimes for HSR will be the exception, if they exist at all, rather than the rule, and will be limited to longer-distance point-to-point trains.

- Any special security measures adopted exclusively for HSR trains should provide a net security benefit, not merely displace the risk to non-HSR trains and passengers. This will be hard to achieve.

- Security measures may focus on the station rather than a particular component of transportation in the station. New or renovated stations should be designed and constructed not only to facilitate security in general but also to accommodate future security environments, including temporary increases in security resulting from developments in security technology, to the extent that these can be forecast—for example, improvements in “stand-off” explosives detection.

- Security measures at stations and prior to boarding should anticipate heightened security situations, including the need to selectively screen more passengers. The measures should be just as easy to lower.

- Security resources should be allocated to save lives, not protect one category of trains or passengers.

- An aviation-security model of 100% passenger inspection does not appear feasible with today's available technology.

- Random screening for both HSR and non-HSR passengers is used increasingly and appears generally acceptable. It also can be increased and decreased, depending on the threat environment.

- The apparent propensity of terrorists to attack the rails of HSR lines, hoping to cause disastrous derailments, suggests that rail security measures should be given close attention.

- While security measures are understandably driven by the bloodiest incidents, disruptions caused by objects on the tracks, false signals (red flares), and threats (accompanied by real or hoax devices to establish credibility) requiring inspections and patrolling also should be considered in security planning.

- Given the importance of train control and signaling in HSR systems, cyber security must also be given appropriate attention.

II. TERRORIST ATTACKS ON HIGH-SPEED RAIL

All but one of the 33 attacks on HSR systems recorded in the MTI Database of Terrorist and Serious Criminal Attacks on Public Surface Transportation occurred in countries where HSR is most highly developed—32 in Europe and one in Japan (see Table 2). However, the countries that account for the greatest number of terrorist attacks on surface transportation are India and Pakistan. Of course, this is too tiny a universe to allow statistical analysis. Nonetheless, the data suggest some patterns.

Table 2. HSR Attacks, by Country

Country	# Attacks	% of Total	Fatalities	Injuries	Avg FPA	Median FPA	Avg IPA	Median IPA
Germany	10	30.3%	0	0	0.0	0.0	0.0	0.0
France	9	27.3%	5	37	0.6	0.0	4.1	0.0
Spain	6	18.2%	0	0	0.0	0.0	0.0	0.0
Russian Federation	3	9.1%	27	155	9.0	0.0	51.7	0.0
United Kingdom	2	6.1%	0	1	0.0	0.0	0.5	0.0
Switzerland	1	3.0%	0	0	0.0	0.0	0.0	0.0
Japan	1	3.0%	0	0	0.0	0.0	0.0	0.0
Italy	1	3.0%	0	0	0.0	0.0	0.0	0.0
TOTALS AND AVERAGES	**33**	**100.0%**	**32**	**193**	**1.0**	**0.0**	**5.8**	**0.0**

Table 3 shows that 19 of the 33 attacks targeted high-speed trains; nine targeted the railway tracks, but this is a bit misleading, since 11 of the 19 attacks were attempts to derail the trains by sabotaging the rails. The nine attacks listed in Table 3 as targeting the railway tracks were not clearly intended to derail a train; they may have been intended simply to cause damage or disrupt service.

Table 3. HSR Attacks, by Target

Target	# Attacks	% of Total	Fatalities	Injuries	Avg FPA	Median FPA	Avg IPA	Median IPA
Train, Passenger (Intercity of Commuter)	19	57.6%	32	193	1.7	0.0	10.2	0.0
Railway Tracks	9	27.3%	0	0	0.0	0.0	0.0	0.0
Train Service Facility or Equipment	2	6.1%	0	0	0.0	0.0	0.0	0.0
Railway Signals or Comm. System	2	6.1%	0	0	0.0	0.0	0.0	0.0
Railway Tunnel	1	3.0%	0	0	0.0	0.0	0.0	0.0
TOTALS AND AVERAGES	**33**	**100.0%**	**32**	**193**	**1.0**	**0.0**	**5.8**	**0.0**

This becomes clearer in Tables 4 and 5. As shown in Table 4, a total of 11 attacks were aimed at causing a derailment using an IED or mechanical means. Nine other attempts involved bombs or IEDs; seven involved IIDs; three involved arson. Table 5 provides a breakdown of derailment attempts.

Table 4. HSR Attacks, by Attack Method

Attack Method	# Attacks	% of Total	Fatalities	Injuries	Avg FPA	Median FPA	Avg IPA	Median IPA
IED, Unspecified	9	27.3%	5	37	0.6	0.0	4.1	0.0
IID (Improvised Incendiary Device)	7	21.2%	0	0	0.0	0.0	0.0	0.0
Derailment, Confirmed Track Bomb - IED, Unspecified	7	21.2%	27	155	3.9	0.0	22.1	0.0
Sabotage, Other	3	9.1%	0	0	0.0	0.0	0.0	0.0
Arson	3	9.1%	0	0	0.0	0.0	0.0	0.0
Derailment, Suspected Track Bomb - IED, Unspecified	1	3.0%	0	0	0.0	0.0	0.0	0.0
Derailment, Suspected Bolts/Tracks Removed	1	3.0%	0	0	0.0	1.0	0.0	0.0
Derailment, Other or Unknown	1	3.0%	0	0	0.0	0.0	0.0	0.0
Derailment, Confirmed Bolts/Tracks Removed	1	3.0%	0	1	0.0	0.0	1.0	0.0
TOTALS AND AVERAGES	**33**	**100.0%**	**32**	**193**	**1.0**	**0.0**	**5.8**	**0.0**

Table 5. HSR Attacks, by Derailment Method

Derailment Attack Method	# Attacks	% of Total	Fatalities	Injuries	Avg FPA	Median FPA	Avg IPA	Median IPA
Derailment, Confirmed Track Bomb - IED, Unspecified	7	63.6%	27	155	3.9	0.0	22.1	0.0
Derailment, Suspected Track Bomb - IED, Unspecified	1	9.1%	0	0	0.0	0.0	0.0	0.0
Derailment, Suspected Bolts/Tracks Removed	1	9.1%	0	0	0.0	1.0	0.0	0.0
Derailment, Confirmed Bolts/Tracks Removed	1	9.1%	0	1	0.0	0.0	1.0	0.0
Derailment, Other or Unknown	1	9.1%	0	0	0.0	0.0	0.0	0.0
TOTALS AND AVERAGES	**11**	**100.0%**	**27**	**156**	**2.5**	**0.0**	**14.2**	**0.0**

Only one of the attacks aimed at derailment resulted in fatalities as well as injuries; however, it accounted for the majority of the fatalities suffered in all the HSR attacks, and two more caused injuries. It appears that 10 of all the 33 attacks (and possibly a couple more) were intended to cause casualties, while 19 clearly were not. No judgment can be made in two cases.

Table 5 shows that bombs were the terrorists' preferred way to derail a train, but of the 11 attempts, only one succeeded in causing fatalities (the 2009 derailment of the Nevsky Express). This was the second attempt on the same route. In 2007, terrorists derailed the Nevsky Express by detonating a bomb just before a bridge. The bomb exploded under the locomotive, knocking it off the tracks, but the train stayed on the roadbed thanks to the flange rails on the bridge. No one died in the 2007 attack, but 60 people were injured. In 2009, the attackers used a much larger explosive charge which hurled a coach into the air, derailing the cars that followed.

Table 6 looks specifically at the 24 bomb attacks. Fifteen were aimed at high-speed trains, eight at railway tracks or tunnels.

Table 6. HSR Bomb Attacks, by Target

Target	# Attacks	% of Total	Fatalities	Injuries	Avg FPD	Median FPD	Avg IPD	Median IPD
Train, Passenger (Intercity or Commuter)	15	62.5%	32	192	2.1	0.0	12.8	0.0
Railway Tracks	7	29.2%	0	0	0.0	0.0	0.0	0.0
Railway Tunnel	1	4.2%	0	0	0.0	0.0	0.0	0.0
Railway Signals or Comm. System	1	4.2%	0	0	0.0	0.0	0.0	0.0
TOTALS AND AVERAGES	**24**	**100.0%**	**32**	**192**	**1.1**	**0.0**	**6.6**	**0.0**

As Table 7 shows, the 24 attacks involved 29 devices. Significantly, 23 were placed on the tracks or near a train or other target. Only three were placed in the passenger compartment.

Table 7. HSR Bomb Attacks, by Device Delivery Method

Method of Delivery	# Devices	% of Total	Avg FPD	Median FPD	Avg IPD	Median IPD	Avg FPDE	Median FPDE	Avg IPDE	Median IPDE
Placed on Railroad Track or Bridge, or Near a Train	22	75.9%	1.2	0.0	7.1	0.0	3.9	0.0	22.1	0.0
Concealed/Placed in Pax Compartment, Unspecified or Other	3	10.3%	1.7	0.0	12.3	0.0	1.7	0.0	12.3	10.0
Unknown	3	10.3%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Placed Near Train, Bus or Other Target, Unspecified	1	3.4%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
TOTALS AND AVERAGES	**29**	**100.0%**	**1.1**	**0.0**	**6.6**	**0.0**	**2.7**	**0.0**	**16.0**	**0.0**

The outcomes of the bombing attempts are shown in Table 8. Twelve of the 29 devices detonated on target. At least five malfunctioned in some way; 11 others were discovered and rendered safe.

Table 8. HSR Bomb Attacks, by Outcome

Outcome	# Devices	% of Total	Fatalities	Injuries	Avg FPD	Median FPD	Avg IPD	Median IPD
Detonated or Released on Target	12	41.4%	32	192	2.7	0.0	16.0	0.0
EOD Successful, Rendered Safe	11	37.9%	0	0	0.0	0.0	0.0	0.0
Detonated Early or Away from Target, or Malfunctioned	3	10.3%	0	0	0.0	0.0	0.0	0.0
Failed to Detonate or Release	2	6.9%	0	0	0.0	0.0	0.0	0.0
Unknown	1	3.4%	0	0	0.0	0.0	0.0	0.0
TOTALS AND AVERAGES	**29**	**100.0%**	**32**	**192**	**0.2**	**0.0**	**1.3**	**0.0**

III. HIGH-SPEED RAIL ACCIDENTS AND THEIR SECURITY IMPLICATIONS

One of the long-standing theories of transportation safety is that the speed at which a vehicle is traveling is directly associated with the severity of injuries and property damage resulting from an accident. The evolution of HSR directly challenges this assumption. HSR systems throughout Europe and Asia have been working over the past 50 years to continually improve safety and increase speed.

We reviewed HSR safety incidents, primarily in Western Europe and East Asia, to identify vulnerabilities and gather insights into the possible consequences of terrorist attacks against HSR systems. Our information sources include investigations conducted by government agencies, such as the National Transportation Safety Board (NTSB) in the United States; operating railroads in European and Asian countries; trade and public media reports; railroad press releases; technical reports; and Internet-based forums. Unfortunately, the majority of countries operating HSR systems do not make official accident reports publicly available. This presented some obstacles to collecting or verifying specific data on train speeds, passengers on board, and numbers of injuries or fatalities.

However, our primary challenge was in delineating which incidents involved HSR services and equipment and which did not. More often than not, reports regarding derailments, collisions, or other incidents on “high-speed trains” concerned commuter or intercity trains moving well under 100 mph and designed with top speeds of less than 120 mph. The moniker “high-speed” is sometimes used regardless of whether the service meets any of the industry’s HSR definitions. In many cases, the label is applied to describe a new service that is merely significantly faster than prior service on a particular corridor.

According to the International Union for Railways (UIC), which defines HSR as lines or sections with operating velocities greater than 155 mph, HSR systems are currently operating in 13 countries in Europe and Asia, and one is operating in the United States. Another six countries have new systems in the construction phase or on the drawing board (see Table 9).

Table 9. Miles of High-Speed Lines in the World

Country	In Operation	Under Construction	Planned
Europe			
France	1,265	470	1,496
Germany	829	266	347
Italy	574	0	245
The Netherlands	75	0	0
Poland	0	0	442
Portugal	0	0	625
Russia	0	0	404
Spain	1,332	1,043	1,058
Sweden	0	0	466
Switzerland	22	45	0
United Kingdom	70	0	127
Asia			
China	3,979	2,632	1,803

Country	In Operation	Under Construction	Planned
Taiwan	214	0	0
India	0	0	1,496
Japan	1,655	263	347
Saudi Arabia	0	342	245
South Korea	256	116	0
Turkey	278	471	442
United States			
Northeast Corridor	149	0	
LA–Sacramento	0	0	559

Note: As of July 1, 2012, lines or sections in which operating velocity was greater than 150 mph.
Source: UIC High Speed Department.

Europe

Belgium: Thalys

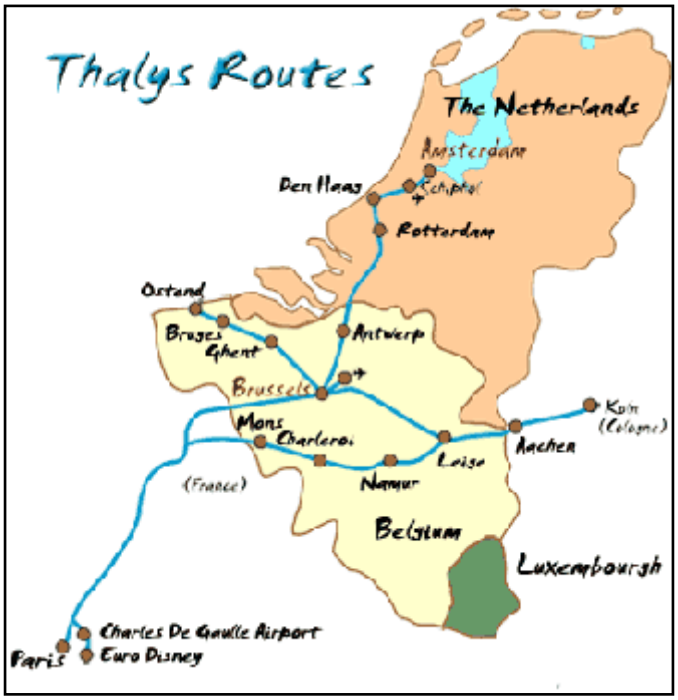

Figure 1. Thalys Route Map

Thalys is a joint service offered by the Belgian, French, and Dutch railways. The system is centered in Brussels, with three primary lines radiating outward (Figure 1). Two of the lines, one to Paris and one to Amsterdam, are also shared by the Eurostar service, and the third extends into Cologne, Germany. A fourth line extends northwest from Brussels to the city of Ostend, on the North Sea. A separate line leaves the Paris-Brussels line near the France-Belgium border, traveling through the cities of Mons, Charleroi, and Namur before joining the Brussels-Cologne line in Liege, essentially providing a southern bypass around Brussels. Service extensions now also include routes to Dusseldorf and Essen from Cologne and a line to Avignon and Marseille, south of Paris. Trains between Paris and Brussels, Brussels and Aachen, and Antwerp and Amsterdam use a variety of dedicated HSR lines. The remaining service runs primarily on conventional tracks.

Thalys uses two types of trainsets: PBA and PBKA. The PBA sets can operate under standard French voltages, also used in the Netherlands, as well as the 3-kv DC supplies used in Belgium and Italy. They include a power car on each end, with prime movers, engineer's cabs, and no passenger seating; and eight cars with a capacity of 377 passengers. They have a maximum operating speed 185 mph and are pressure-sealed to reduce passenger discomfort when entering and exiting tunnels. The PBKA sets are similar to the PBA sets in length, number of cars and seats, and operating speeds but use different power cars. Both the PBA and PBKA sets are single-level and use articulated coaches that share bogies or wheelsets between each coach and independent bogies on the power cars, allowing them to separate from the rest of the train without jacks or lifts.

Finland: VR Pendolino

The state-owned VR (Figure 2) is responsible for managing the passenger and freight rail services in Finland. In 2010, the railway network infrastructure maintenance and construction functions were divested into the Finnish Transport Agency. Although the term Pendolino is a brand name of Fiat (later, Alstom) for a line or "family" of tilting trains, it is also the service brand used by the VG Group for their high-speed services. The service uses Pendolino (VR Class Sm3) trainsets built by Rautaruukki-Transtech between 2000 and 2006. The trains are capable of 140 mph service, although existing lines have limited their typical operation to less than 120 mph.

Figure 2. VR Pendolino Route Map

In 2006, the first segment of 140 mph track was opened between Kerava and Lahti. Its 18 trainsets are all configured in the same fashion: 18 cars, including two end coaches

with engineer's cabs that are in either the leading or trailing position and a total passenger capacity of 309. Domestic service is currently offered on five separate routes radiating from Helsinki, with two to 10 trains per day, depending on the route.

A new HSR service was introduced in 2010 as a joint venture between the VR Group and the Russian Railways (RZhD) under the name Karelian Trains Ltd. The new service, using Alstom Pendolino Sm6 trains, is branded Allegro and has reduced train travel time between Helsinki, Finland, and St. Petersburg, Russia, from 5.5 hours to 3 hours. The seven-car trainsets have a capacity of 377 passengers.

France: TGV

France's TGV (train à grande vitesse) started its HSR service between Paris and Lyon in 1981. The TGV HSR network operated by Société Nationale des Chemins de fer Français (SNCF) now consists of eight lines, all radiating from Paris, and extends into Belgium, Luxembourg, Germany, Switzerland, Spain, and Italy (Figure 3). In addition to operating the country's 20,000-mile rail network, SNCF has become a multinational powerhouse in railroad consulting, construction, and operation. In 1997, an EU directive forced SNCF to divest ownership of the rail infrastructure to a separate, government-owned entity, Réseau Ferré de France. SNCF and its partner Alstom have successfully exported the TGV technology to HSR operations in Spain, Taiwan, South Korea, and Belgium.

Figure 3. TGV Route Map

TGV runs high-speed trains on two types of lines: LGV and Lines Classiques. LGV lines were designed and built specifically for dedicated use by high-speed trainsets. They have no level road crossings, and they have ROW fences and barriers that significantly reduce or prevent trespassing by vehicles, humans, and animals, all of which can significantly damage and/or derail trainsets and lead to injuries and fatalities.

Lines Classiques are mixed-use systems that run freight, intercity, and HSR service. Further differences between LGV and Lines Classiques include:

- Track curvature: LGV lines are constructed with larger-radii curves and longer approaches into the curves, allowing for higher-speed operations without increased centripetal force.

- Track cant: The cant or super-elevation of a track is the horizontal angle or slope of a track through a curve. The cant is kept to a minimum on Lines Classiques, whereas on LGV lines, the cant is maximized to allow for better track adhesion and train equilibrium.

- Track gauge: The gauge tolerances on LGV lines are significantly lower, and design standards are much more precise.

- Track components: LGV lines, like most other dedicated HSR lines throughout the world, are built with more cross-ties, or sleepers, per mile than traditional lines. These ties are made of reinforced concrete, either solid or monobloc or bibloc (two smaller concrete ties that sit directly under the rail), connected by a steel reinforcing bar. The rail is fastened, not spiked, to the ties with a variety of clips and often has a rubber or other material pad separating it from the tie to absorb and dampen vibration and noise while reducing friction wear.

- Track bed: The underlayment of LGV track structure is typically ballast, like that of most other railroads, but the bed of ballast is much deeper.

- Switches: LGV lines in France and many other HSR systems use swingnose or movable frog switches that allow for safe crossovers up to 100 mph.

- Catenary: All HSR overhead electrification must be built to maintain greater mechanical tension than other catenary applications on commuter rail or rail transit systems.

- Signaling: On LGV lines and other systems throughout the world that achieve and exceed 200 mph continuous operations, traditional wayside signals are not usable.

TGV currently uses eight types of trainsets running at maximum speeds of 170 mph to 200 mph, depending on the trainset design and operating line. While the trainsets range in length and seating capacity (from roughly 350 to 750 passengers), all share a common design trait: In addition to a power car at each end of the train, all of the intermediate cars “share” a truck or bogie at each end. Although this design makes separating trainsets for

service or other reasons extremely difficult, it has been credited with keeping the trainsets vertical and linear in several incidents, including the December 1992 derailment of a train travelling 182 mph when the track gave way because of a large sinkhole.

There have been 17 TGV HSR accidents (both LGV and Lines Classiques) since service began. Of these, 11 (65%) involved collisions at grade crossings. After its first HSR grade-crossing collision, in September 1988, TGV improved the crash-protection safety features of its trainsets, significantly reducing injuries and deaths caused by collisions.

Germany: ICE

The West German National Railway, Deutsche Bundesbahn, began testing an experimental high-speed train developed by a Siemens Corporation–led consortium in 1984. The first InterCityExpress (ICE) service was launched in 1991 between Hamburg and Munich. Service to Bremen and Nuremburg began a year later (Figure 4). In 1994, a few years after the reunification of Germany, the assets and operations of Deutsche Bundesbahn and Deutsche Reichsbahn, the former East German national railway, were merged into Deutsche Bahn AG (DBAG). DBAG is a private, publicly traded multinational corporation divided into four separate operating entities: DB Bahn, which provides passenger rail service in Germany; DB Netze, which is responsible for the nation's rail infrastructure and operations; DB Schenker, a freight rail and logistics operation; and Arriva, which provides contract passenger rail services in the UK.

Figure 4. ICE Route Map

DB Bahn is further broken into three business units: DB Stadtverkehr, which operates multiple bus companies and provides commuter rail service in Hamburg and Berlin; DB Fernverkehr, the provider of all high-speed and non-HSR intercity passenger service, including ICE, in Germany; and DB Regio, which provides non-HSR short- and medium-distance service.

ICE rolling stock includes 259 trainsets in five variants: ICE 1, ICE 2, ICE 3, ICE T, and ICE TD (diesel powered), all manufactured by Siemens or Siemens-led partnerships. The most current iteration, ICE 3, is an eight-passenger-car, two-power-car configuration, with a capacity of approximately 450 passengers and sustained speeds of 200 mph. Except in the 186 mph, 107-mile corridor from Nuremburg to Ingolstadt, halfway to Munich, most ICE trains are limited to 170 mph or slower operations. Unlike SNCF and JR Group, DBAG has implemented almost all ICE services on existing rail lines that continue to serve freight rail and slower-speed intercity and commuter rail operations. This shared-corridor relationship has been the catalyst for DBAG and its vendors to aggressively develop and refine the technology for tilting trains, allowing for higher-speed operations on curves, with negligible super-elevation.

ICE is the most multinational HSR operation in the world, providing service throughout Germany and across the borders of France, Belgium, Switzerland, Austria, Denmark, and the Netherlands. Similar to TGV, ICE technology—primarily trainset designs and configurations—has been exported to Spanish HSR operator RENFE, to China for the Beijing-to-Tianjin HSR service, and to Russia for the St. Petersburg-to-Moscow Sapsan service that is replacing the Nevsky Express.

Italy: Trenitalia

Figure 5. Trenitalia Route Map

Like those of other EU countries, Italy's railroad network and operations were reorganized at the turn of this century as a result of EU deregulation and directives. The Rete Ferroviaria Italiana (RFI), a subsidiary of Ferrovie dello Stato (FS), owns and operates the Italian railway network infrastructure, providing signaling, train control, and maintenance. FS is an Italian-owned government company responsible for all of the country's rail operations and infrastructure. Another subsidiary of FS is Trenitalia, the primary operator of all freight and passenger train service, including HSR, in the country (Figure 5). In 2012 Trenitalia began to face new competition from Nuovo Trasporto Viaggiatori (NTV).

Trenitalia began offering HSR service between Rome and Milan in 1989. It currently offers HSR service on two primary corridors: Turin to Venice via Milan, and Milan to Salerno via Bologna, Florence, Rome, and Naples. Depending on the trainset series and length/configuration, Trenitalia HSR trains can run at maximum speeds of between 155 mph and 210 mph and can carry between 390 and 570 passengers.

Spain: RENFE

Spain has the second largest network of HSR lines in the world (Figure 6). In 1941, its railways were nationalized, forming Red Nacional de los Ferrocarriles Españoles (RENFE). Since 2005, when an EU directive mandated the separation of track ownership from operations, the country's rail infrastructure has been under Administrador de Infrestructuras Ferroviarias (ADIF), which is responsible for the management, maintenance, and construction functions associated with RENFE, including high-speed-passenger and conventional, mixed-use lines.

RENFE handles Spain's rail activities in four divisions: commuter and medium-distance high-speed and conventional passenger trains; long-distance high-speed and conventional passenger trains; freight service; and rolling stock acquisition and maintenance. Long-distance HSR service is offered under the brand name Alta Velocidad Española (AVE), which runs service on four primary dedicated HSR lines radiating from AVE's operational hub in Madrid. HSR trains reaching 185 mph operate out to Barcelona, Valladolid, Seville, and Valencia. Medium-range, dedicated HSR network service is provided under the name AVANT on portions of the longer lines or on short extensions or branches. Connecting or extending past the primary and secondary cities on the HSR network is the ALIVIA service. This operation uses high-speed trainsets, capable of 140 mph to 160 mph, running long-distance service on dedicated HSR lines and conventional, mixed-use lines. A fourth and much smaller brand of service is Euromed, which runs south from Barcelona, along the Mediterranean coast, to Valencia and Alicante. The Euromed operation utilizes six trainsets, derived from TGV Atlantique and Reseau designs, and travels predominantly on conventional lines.

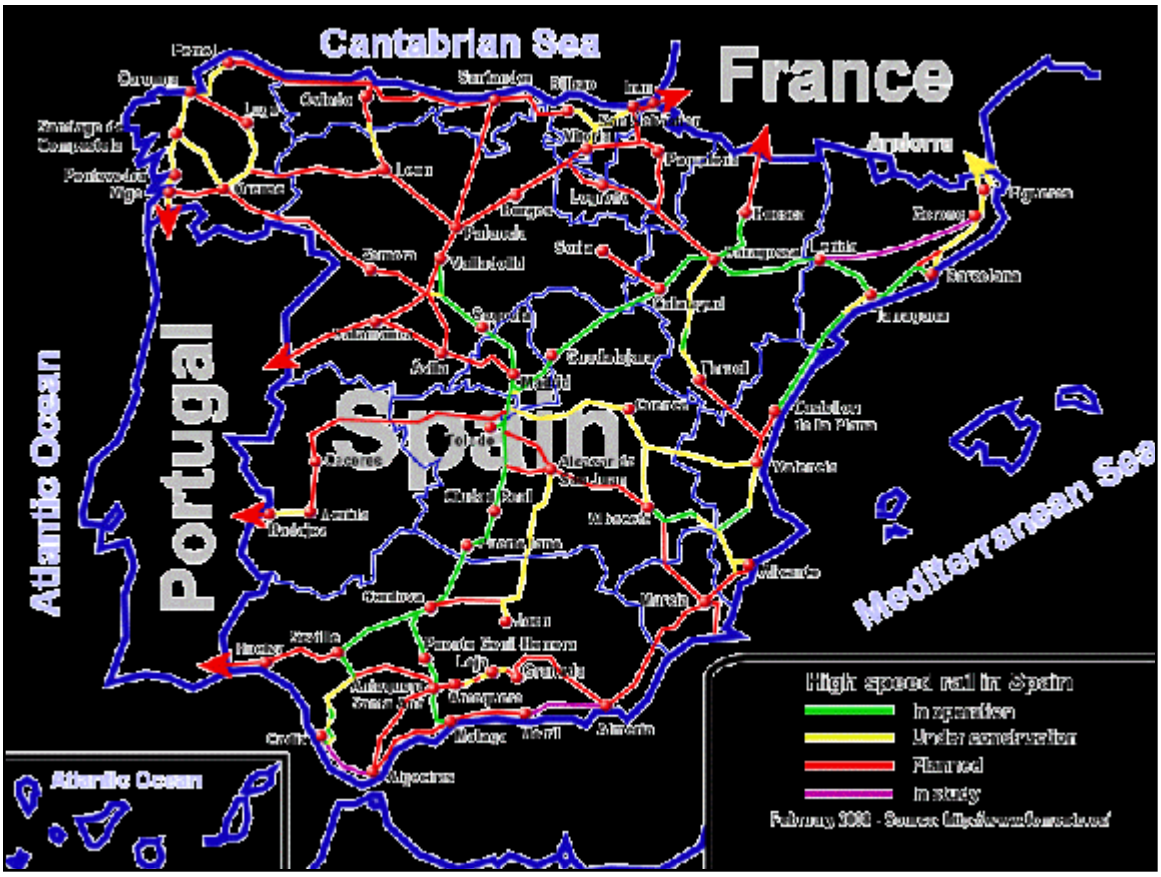

Figure 6. RENFE Route Map

As in most countries, the differences between newly constructed, often-dedicated HSR lines and conventional, possibly mixed-traffic routes are in the design and construction of the overhead catenary, grade separations, and the elevation and construction of track tangents and curves. RENFE currently utilizes 12 different trainset designs and configurations from up to six separate manufacturers or consortiums. Operating speeds in the fleet range from 140 mph to 217 mph, and capacities range from 300 to 400 passengers. The configurations differ in length, from four cars to 13 cars (11 coaches plus two power cars), with some sets utilizing power cars, while others are electrical multiple units (EMUs) with engineer's cabs in end cars.

Sweden: SJ-2000

Bergslagernas Järnvägar and other, smaller private railroads in Sweden, some dating back to the 19th century, were nationalized in 1948, forming the Royal Railway Board, which in turn became the Swedish State Railways, also known as Statens Järnvägar (SJ) (Figure 7). The country's railroad infrastructure was transferred to the Swedish Rail Administration in 1998, and the remaining operations and assets were divided up into seven separate government-held companies. A "new" SJ corporation was formed in 2000 from the public transport division of its predecessor and is now the primary passenger-train operator in Sweden. The Swedish Rail Administration was merged into a larger government agency in 2009, along with the road and maritime administrations, to form the Swedish Transport

Administration, which now owns and maintains all state-owned roads and railroads and is responsible for planning in all modes of transportation.

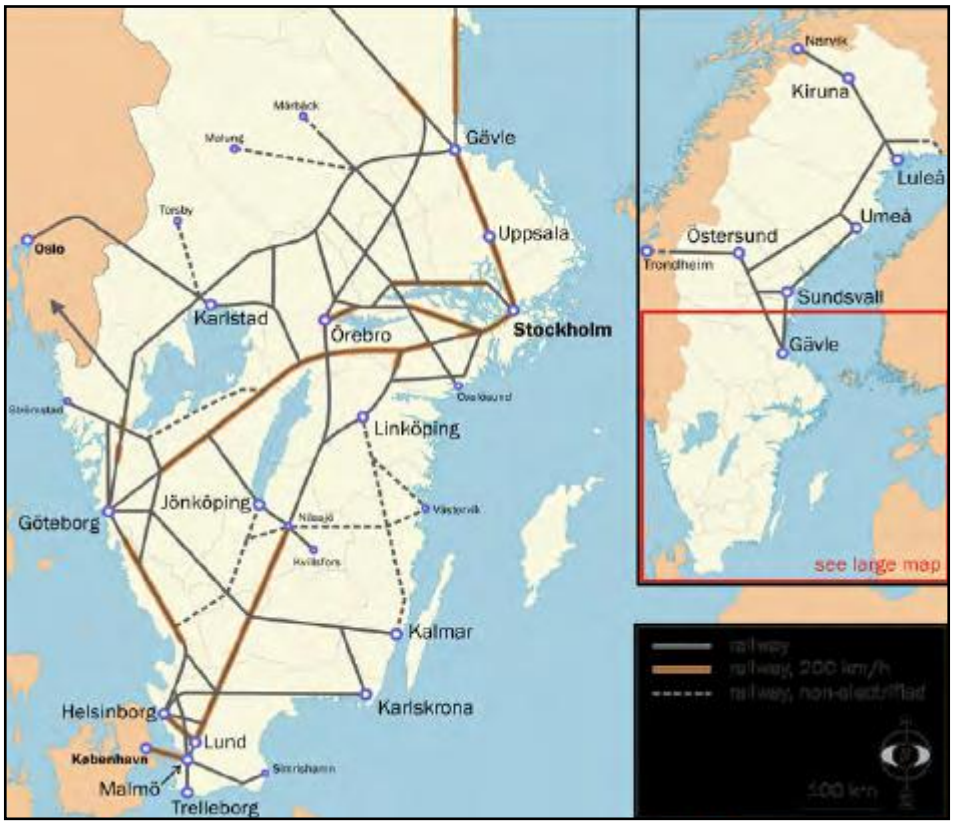

Figure 7. SJ-2000 Route Map

Operating at the low end of the HSR spectrum, with a top speed of 130 mph, the SJ-2000 high-speed train (previously and more commonly known as the X-2000) was launched in 1990. From the beginning, the X-2000 was a unique operation in several ways. It was the first HSR train—as opposed to older steam- and diesel-powered intercity trains—to offer only first-class service. Second-class service was introduced in 1995. The external design of the X-2000 harked back to the early days of streamlined passenger rail service, incorporating fluted or ribbed stainless-steel sides on the power cars and the coaches. Unlike Japan and France, Sweden chose not to build any new HSR infrastructure and runs X-2000 on an existing rail system, continually shared with lower-speed passenger and freight trains. Owing to this decision, SJ has invested considerable time and resources into train-tilting technology and steerable trucks, or bogies.

The configuration of the X-2000 trainsets is also unique among HSR rolling stock. HSR trainsets typically have a power car at each end, with unpowered coaches in between, or are EMU designs, with either power-collection pantographs and/or powered axles with traction motors on all or several cars in a set. The typical X-2000 consists of a single power car, four unpowered coaches, and an unpowered coach with an engineer's cab at the rear. This design allows SJ to add cars, up to a maximum of 16, to a trainset, providing a maximum capacity of 1,600 passengers. While in form and function the X-2000 is an HSR trainset, operationally it is an electric-locomotive-hauled passenger train. The X-2000's

steerable, or “soft,” bogies adjust automatically on curves, with axles that pivot laterally with the frame, allowing the train to reach speeds 40% greater than conventional rolling stock without increasing stresses on the track or the wheel/rail interface. Tilting technology also permits the train to operate at higher speeds on less-super-elevated curves while maintaining passenger comfort, by shifting the train’s center of gravity and reducing the lateral forces pulling it to the outside of a curve.

Like other HSR equipment, the X-2000 uses an automatic train control system that provides information to the engineer up to 2.5 miles in advance of his location. If the information is not acknowledged or appropriately replied to, the train brakes are applied automatically. The train also uses three independent braking systems: an electric regenerative brake for speed adjustments; air-operated disc brakes for normal, or “hard,” braking; and a magnetic track brake for use in emergencies. Using the air-operated brakes, the train will take 1.1 miles to stop when moving at 125 mph. Applying the magnetic track brake when moving at the same speed will stop the train in 0.75 mile.

United Kingdom: Eurostar

There are two primary routes in the Eurostar system: London to Brussels and London to Paris. Seasonal service is offered south of Paris to Avignon and Bourg-Saint-Maurice (Figure 8). Every Eurostar train operates out of St. Pancras Station in London, through the Channel Tunnel, to Lille in northern France. At Lille, trains head either south to Paris or other seasonal destinations or northeast to Brussels.

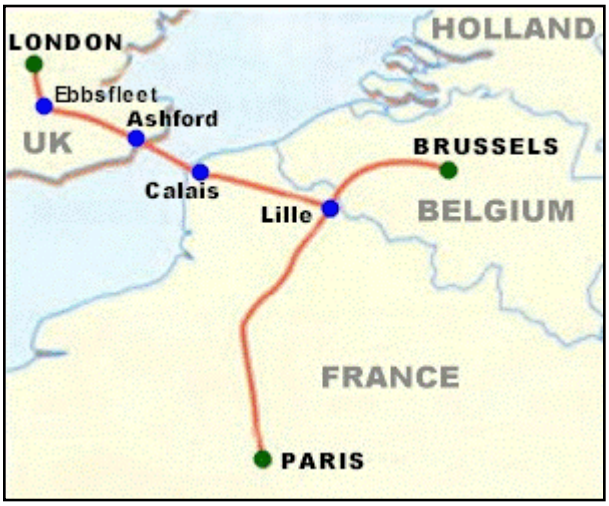

Figure 8. Eurostar Route Map

Eurostar’s most iconic feature and prime safety and security challenge is the Channel Tunnel. Opened in 1994, the tunnel provided the first-ever surface-transportation connection between the UK and the rest of Europe. Eurotunnel S.A., a publicly traded company that was formed to design, build, and operate the tunnel, brings in revenue by charging Eurostar and other, non-HSR operators fees for using the tunnel. Stretching 31.4 miles from Folkstone in the UK to Coquelles in France, the tunnel includes two 24-foot-diameter running tunnels and a 16-foot-diameter service tunnel. The service tunnel, located

between the two running tunnels, is kept at a higher pressure to prevent smoke or fumes from entering (similar to stairwells in high-rise buildings) and is connected to the two other tunnels by passageways located every 1,230 feet from portal to portal. The tunnel also includes two large caverns, one 7.5 miles from the French shore line and the other 4 miles south of Shakespeare Cliff in the UK. These two caverns house crossovers between the north and south running tunnels, allowing trains to bypass sections that are closed due to emergencies or routine maintenance.

Eurostar uses only one type of trainset, built by Alstom, which also built the TGV fleet of trainsets. It has 20 cars and 750 seats and comprises two power cars with no passenger seating and 18 coaches. The trains can operate at 185 mph. The major difference between the Eurostar and TGV trainsets is a smaller cross-section due to tighter right-of-way clearances in the UK. For safety reasons, the Eurostar trains comprise two half-sets. The contiguous ends of coaches 9 and 10 do not share a wheel set or bogie, unlike the articulated connections between the other 16 coaches. The connection between coaches 9 and 10 uses a Scharfenberg coupler, which allows relatively quick disconnection in the event of an emergency. While articulation has proven to reduce the possibility of jackknifing cars during a derailment or collision, it also eliminates the possibility of operating anything less than a full trainset once it leaves a service yard. The coupler at the center of the train gives Eurostar crews the ability to move passengers to another section of the train in the event of a fire, derailment, collision, or security threat; split the train in half; and move the nonaffected set with the passengers away from the source of danger.

Eurostar trains also operate with two qualified engineers. On each run, the engineer occupies the cab of the lead power car and the Chef du Train, or conductor, occupies the rear-power car cab. If the engineer is injured or killed in an incident, the conductor can uncouple the two halves of the train and operate the back half in reverse, away from the incident scene. This arrangement also helps address hours-of-service issues, since the two individuals switch roles once a train reaches a terminal and reverses direction.

Power is sent to the train's traction motors, located on the four axles of each power car, as well as the unshared bogies on the first and last coaches of the train. Depending on the route, Eurostar trains use four or five signal systems on a single run. These range from warning systems based on 60-year-old technology to the TVM system used on TGV's LGV lines.

In the past 16 years, there have been four instances in which Eurostar trains have stalled in the tunnel, stranding large numbers of passengers for an extended period of time. While no injuries were sustained in these events, long delays could lead to hostile situations between passengers or passengers and crew, as well as dangerous situations for individuals with medical and/or medication needs.

Asia

China: Chinese High-Speed Railway

Although the Chinese Ministry of Railways (MOR) did not begin construction of its first HSR line until 1998, China is now home to the world's largest HSR network. The first line, from Beijing to Tianjin, opened a week before the 2008 Olympics; a little more than four years later, the country had 5,809 miles of high-speed lines with trains traveling 186 mph (Figure 9). The network includes eight primary routes: four north/south lines and four running east and west, concentrating service in the population centers in the eastern portion of the country.

Figure 9. Chinese High-Speed Railway Route Map

A key part of China's HSR plans focuses on developing the domestic intellectual and manufacturing capacity to design and construct HSR trains and infrastructure components. The first bids solicited by the MOR called for a "technology transfer," enabling China's railroad-sector manufacturers to evolve toward majority, if not complete, domestic production of all HSR-related equipment. Alstom, Bombardier, and Kawasaki were awarded parts of an order for 200 trainsets that required them to establish a joint venture with a Chinese company to allow for this technology transfer. A year later, the Siemens Corporation negotiated a deal with MOR and entered into a joint venture to deliver 60 trainsets based on the ICE 3 trains. These partnerships succeeded in meeting China's initial demand for HSR trainsets and jump-starting domestic production. However, claims of patent theft by Kawasaki raised industry concerns over the long-term benefits of such

arrangements. The Chinese manufacturers involved in the joint ventures are now working to export their technology to fledgling HSR operations in Europe, South America, North America, and Asia.

The MOR has developed a domestic signal/train control system based on learning from the European train control system and other foreign practices combined with Chinese technological advancements. The Chinese train control system (CTCS) is segregated into five levels. The first two, CTCS-0 and CTCS-1, use track circuits to identify occupied track and set wayside and cab signals appropriately. CTCS-2 is used in 125 to 155 mph territory and incorporates more-advanced track circuit detection and communication technology with automatic-train-protection (ATP) features that initiate proper braking procedures similar to automatic train control systems in Europe and North America. CTCS-3 incorporates wireless wayside-to-train communications similar to TGV's system on its LGV lines. CTCS-3 is used on routes where speeds can reach 186 to 217 mph. Like the TGV LGV, operations at this speed cannot rely on wayside signals because of reaction time and must incorporate wireless signaling, communication, and train control features, including fail-safe features that can compensate for human error, slow reaction times, and longer stopping distances. The highest level, CTCS-4, is in the research and development phase for implementation in 200 mph and higher-speed operations.

The Chinese HSR network has implemented unique ROW and track construction methods throughout the system. Much of the ROW, particularly through the more densely populated suburban and urban areas, is built on concrete viaducts. More than 85% of the two-track line between Beijing and Tianjin on the Beijing-Shanghai route is elevated on viaducts. While this is a more expensive design, it is also a much faster approach to building a rapidly growing network of HSR trains. All of the new dedicated HSR lines are built using slab or ballastless track. Slab track, which is also being increasingly used in Japan, incorporates fixed concrete panels that have pads on which the rail rests directly and receivers for rail clips. This eliminates the need for ties or sleepers. Much like prefabricated concrete bridges, the slabs are fastened together to form a continuous ROW on which the rails are laid. The slabs are the full width of the track and incorporate channels and ports for proper drainage.

Unlike traditional track, which uses ties with equal or larger spaces in between them, placed on ballast, ballastless track uses ties placed adjacent to each other, with no spacing, on a slab. The initial construction cost of both slab and ballastless track is significantly higher than that of traditional ballast track designs using concrete, wood, or resin ties, but the maintenance costs over the life of the track are much lower. Advocates of slab and/or ballastless track also claim that it provides a smoother ride and greater safety, since defects are less likely to occur and easier to identify.

Japan: Shinkansen

In the wake of World War II, Japanese National Railways (JNR) was organized to redevelop and operate a national rail network. One of JNR's early goals was to design and construct high-speed, or "bullet," passenger trains linking the country's major cities. In 1964, Shinkansen became the world's first HSR system, stretching 340 miles between Tokyo and Shin-Osaka

and running trains at maximum speeds of 130 mph. Shinkansen quickly became an icon of national pride and continued to thrive despite the dissolution of JNR due to financial troubles and the division of its assets and operations among seven separate private-sector companies collectively known as the Japan Railways Group (JR Group).

Today, the Shinkansen network includes more than 1,600 route miles (Figure 10) and operates approximately 900 trains per day at speeds between 150 and 190 mph. It is owned and operated by five private companies of the JR Group: JR Kyushu, JR West, JR Central, JR Hokkaido, and the largest, by far, in terms of system size and passenger volume, JR East. These companies utilize 20 different styles and configurations of overhead electrically powered trainsets with power cars at each end. Capacities per trainset range from approximately 380 passengers on six- and seven-car sets to 1,200 passengers on 12-car bilevel trainsets and more than 1,300 on 16-car sets.

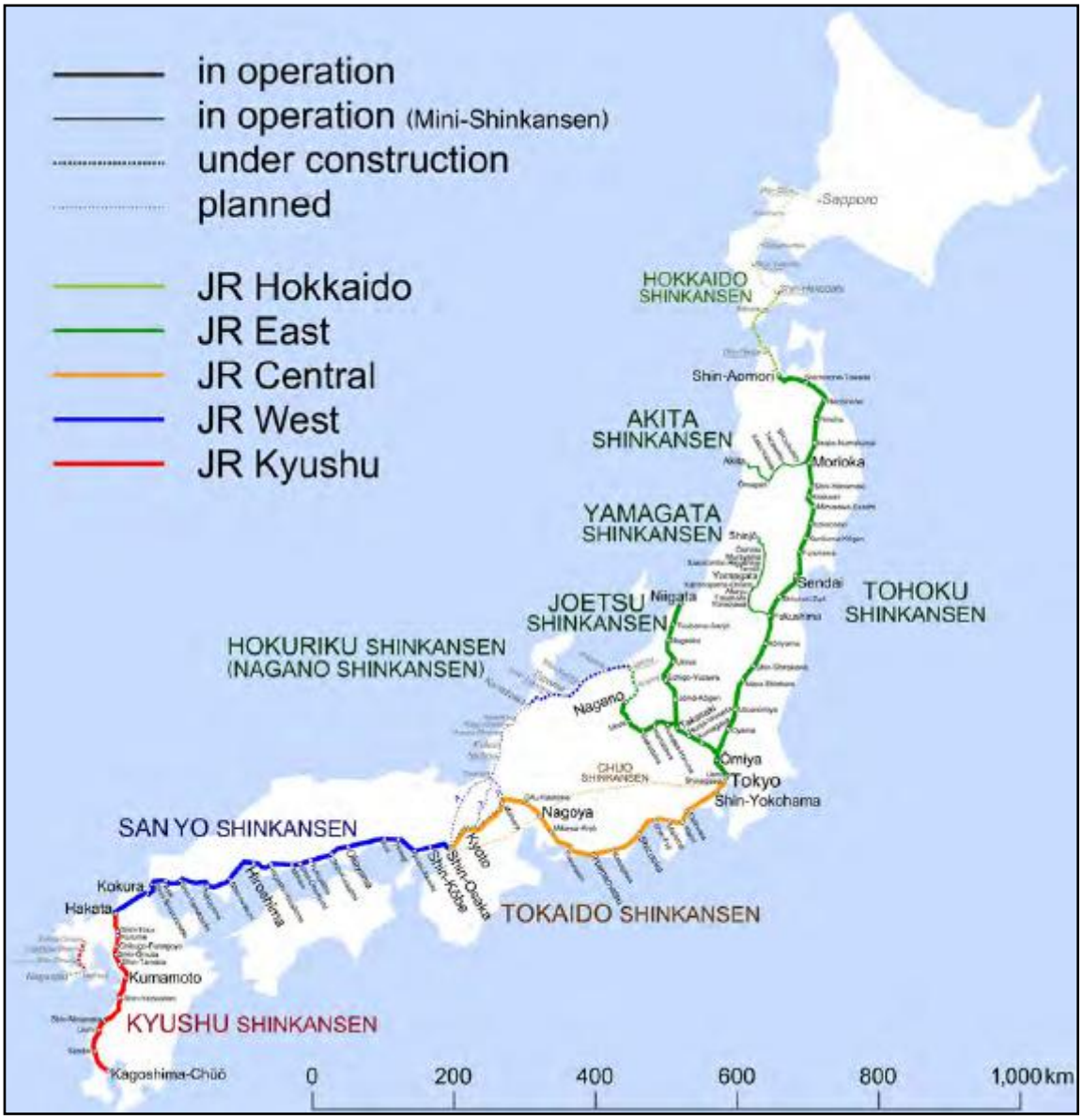

Figure 10. Shinkansen Route Map

Throughout its history, Shinkansen has maintained an exemplary safety record, with only four in-service fatalities, three of which involved persons intentionally jumping from the train to commit suicide. The fourth fatality, in December 1995, was the result of a passenger being caught in the train door.

South Korea: Korean Train eXpress (KTX)

Korail, South Korea's national rail carrier for all levels of freight and passenger service, introduced Korean Train eXpress (KTX) HSR service in April 2004. The Gyeongbu line runs from Seoul to Busan, and the Honam line runs from a junction with Gyeongbu in Osong to Mokpo. Even though HSR trainsets began operating on both lines on the first day of service, the Gyeongbu line was not completed as a dedicated HSR line until November 2010 (Figure 11). Dedicated HSR expansions to the Honam line are scheduled to be completed in 2014 and 2017. Until then, KTX service will operate with HSR equipment on a combination of completed HSR lines and conventional lines.

Figure 11. Korean Train eXpress Route Map

KTX uses the KTX-I trainset, derived from the TGV Reseau. It consists of two power cars and 18 articulated cars, with a capacity of 935 passengers and a top speed of 190 mph. The KTX-I was initially built in France by Alstom but is now produced by Rotem in South Korea. A shorter version called the KTX-II was developed for routes with fewer riders. Consisting of only eight articulated cars and two power cars, the KTX-II has a capacity of 363 passengers and a top speed of 190 mph. A year after its introduction in 2010, Korail asked the manufacturer, Hyundai-Rotem, to take all 19 sets back following a series of 15 malfunctions and train shutdowns, along with the discovery of structural cracks.

United States: Northeast Corridor – Amtrak Acela

Figure 12. Amtrak Acela Route Map

Grade separations, overhead electrification, some super-elevated curves, advanced signaling systems, and the elimination of all but 11 grade crossings have brought Amtrak's Northeast Corridor (NEC) up to respectable HSR corridor standards (Figure 12). Although Acela trains, Amtrak's HSR brand, can reach speeds of 150 mph, track and catenary designs limit much of the operation to 90 to 110 mph. From New Haven south through New York to Washington, DC, the system still has the rigid suspension architecture first developed by its predecessor railroads. If this catenary system is upgraded, the Acela will be able to realize increased speeds on parts of the line, but the curvature of some track and the omnipresent commuter trains sharing the route will always be an obstacle to achieving the speeds the trainsets are capable of.

Because of unique and stringent crashworthiness standards in the United States, proven off-the-shelf trainsets such as the ICE, TGV, or Shinkansen could not be considered for Acela service. Amtrak selected a consortium bid from Bombardier and Alstom in 1996 with a provision that the sets be manufactured in the United States. Using existing facilities, Bombardier built the power cars in Plattsburg, New York, and the coaches were built in Montpelier, Vermont.

The trainset configuration is similar to earlier TGV designs such as the Atlantique and Thalys. It has two power cars, one at each end, and six cars—a first-class coach, a café car, and four business-class coaches. Like the TGV sets, it is semi-permanently coupled and does not use articulated cars sharing bogies/trucks. It also borrowed the traction system, regenerative braking, bogie/truck structure, disc brakes (three rather than four

per axle), and crash-absorption technology from later-generation TGVs. After the adoption of Tier II crash standards by the U.S. Federal Railroad Administration (FRA) in 1999, the car design had to be modified so that the vestibules could effectively act as crash-energy-management or crumble zones in a derailment or collision. This meant that low-level steps and trap doors had to be eliminated from the plans, not only limiting use of the system to service on high-level-platform stations but also complicating evacuation procedures out on the line. Foldable evacuation ladders were installed at each exit on the trains to help alleviate this problem.

Borrowing only the concept from the X-2000, the Acela trainsets incorporated tilting technology from Bombardier's 1980 design for the Light-Rapid-Comfortable (LRC) trains used by VIA Rail in Canada. This allowed for faster speeds on curves that were not super-elevated by shifting and lowering the center of gravity and reducing passenger discomfort with lateral G-forces.

The trainsets also included other "firsts" on North American passenger trains: The power cars were equipped with emergency evacuation hatches in the engineer-cab roofs, and standpipe connections were installed on both sides to allow firefighters to flood the engine compartment without having to perform interior firefighting operations in the unit. Each car of the train was also designed with a "cut spot" in the roof. This area is free of any electrical conduit, structural members, or other obstacles and is clearly marked. It provides a clear spot through which rescue personnel could cut their way if a car is rolled over or has material blocking window or door access.

In its 12 years of operation, Amtrak Acela service has had a number of tragic pedestrian accidents. Seventeen trespassers have either committed suicide or been killed accidently when walking along or across NEC tracks. Two Amtrak or contractor employees have also been killed and two seriously injured while working on the ROW. Since 2010, following a much-needed infusion of capital funds, Amtrak has been aggressively working on installing fencing and other barriers on the entire NEC route in the hopes of restricting or deterring trespassing. It has also eliminated trees, brush and extraneous infrastructure immediately adjacent to the rail line, giving engineers a broader view and better reaction time.

HSR Safety Incidents

Of the 12 systems profiled here, ten have experienced one or more serious incidents resulting in fatalities. Half of the incidents involved only one fatality, four of which were suicides. Table 10 provides a breakdown of HSR incidents involving fatalities, by type of incident.

Table 10. HSR Incidents Involving Fatalities

Type of Incident	# of Incidents	HSR Passenger/ Crew Fatalities	Other Fatalities	Total Fatalities
Grade Crossing Collision	5	2	7	9
Equipment Issue	3	110	0	110
Collision with HSR train	1	40	0	40
Collision with other than a HSR train	4	2	2	4
Suicide	4	4	0	4
Total	**17**	**158**	**9**	**167**

Most incidents involving HSR service and equipment, aside from grade-crossing collisions on shared corridors, have been attributed to engineering failures in the design and/or construction of the rolling stock or ROW. Most HSR systems have been designed to include one or more fail-safe features to compensate for operational human error. Table 11 provides a breakdown of incidents by system, primarily incidents involving injuries or fatalities to on-board crew and/or passengers and/or significant damage to rolling stock or the infrastructure. Pedestrian incidents involving employees, passengers, or trespassers are, for the most part, not included. While almost always fatal and tragic, not only for the victim but also for the engineer and crew, the victim's family and friends, and emergency responders, these incidents rarely cause much damage to the rolling stock or track or cause physical injuries to passengers or crew on board. Pedestrian incidents included in the report are those that involved HSR operations or equipment, regardless of whether it was moving, in a station, or in a storage or service.

Table 11. HSR Incidents, by System

HSR System	Years of Operation	# of Incidents	# of Injuries	# of Fatalities	Average Injuries/ Incident	Average Fatalities/ Incident
Shinkansen	49	10	0	4	0.0	0.4
ICE	22	17	164	102	9.6	6.0
TGV	32	17	134	4	7.9	0.2
Eurostar	19	6	14	1	2.3	0.2
Thalys	17	2	6	1	3.0	0.5
RENFE	22	1	142	2	142.0	2.0
Trenitalia	25	4	56	9	14.0	2.3
SJ-2000	24	9	19	1	2.1	0.1
VR Pendolino	7	2	0	0	0.0	0.0
Korean Train eXpress	9	1	1	0	1.0	0.0
Acela	13	3	0	3	0.0	1.0
Chinese High-Speed Railway	15	1	210	40	210.0	40.0
Total	**254**	**73**	**746**	**167**	**10.2**	**2.3**

Appendix A presents a detailed listing of each incident, including the date; line; equipment; train speed; a description; follow-up actions, if any; injuries; and fatalities. It is important to note that more than half of the incidents (38 of the 73), including the world's fastest derailment, did not result in any injuries or deaths.

The world's fastest derailment occurred in December 1992, when a 10-car TGV train traveling at 182 mph on the Paris-Lille LGV Nord line crossed what appeared to be a 10-foot by 20-foot mud puddle. The mud puddle turned out to unsupported track, traversing what was actually a 23-foot-long, 5-foot-deep sinkhole. The engineer felt a small bump and applied the brake. The last four coaches and the trailing power car derailed. Despite the back half of the train derailing, the trainset remained upright and in line with the track. Accident investigators attributed this to the design of the shared bogies in the trainset and the trainset's relative stiffness. Of the 200 passengers on board, one was slightly injured and one was treated for shock.

The average injuries per incident and average fatalities per incident are actually driven by nine events that resulted in more than 20 injuries and between 0 and 101 deaths. Those nine events are described below.

THE NINE MOST SERIOUS HSR INCIDENTS

1. ICE – June 1998

On June 3, 1998, an ICE 1 train traveling at 125 mph derailed near the town of Eschede, in northern Germany. Like many incidents, particularly those with tragic outcomes, the "Eschede disaster" was preceded by a series events that, if altered, could have either prevented the accident and/or significantly reduced the magnitude of the tragedy.

In the late 1990s, DBAG discovered that the single-cast, solid-steel wheels on the ICE 1 trainsets were wearing unevenly, becoming "unround" over time. This process caused vibrations that were being transmitted into the car bodies of the train. The ICE 2 and later-generation sets included pneumatic suspensions, which prevented the vibration problems inherent in the steel-spring bogie suspensions of the ICE 1 trainsets. All ICE 1 trainsets were retrofitted with new Bochum 84 wheels that had cast steel centers mounted onto an axle with bearings. A rubber ring upon which another cast steel tire was mounted was placed around the cast steel center. The rubber between the two cast-steel components of the wheel was intended to be a vibration absorber, yielding a smoother ride. While the wheels initially served their purpose at all speeds of operation, the design induced significant and unexpected fatigue, ultimately causing cracks in the outer steel tire. These cracks were very difficult to detect because they occurred on the inner part of the wheel, where the steel tire met the rubber insert.

About 3.5 miles before the ICE 1 accident site, a steel tire on the third axle of the first passenger car behind the lead power car cracked apart, and a substantial piece punctured the floor of the car. A passenger quickly alerted the conductor, who was in the third coach, but the conductor did not have the power under DB rules to stop the train until he visually inspected the problem. In the one minute it took for the passenger to make notification and the conductor to return to the affected car, the train traveled a little over 2 miles. At that moment, it went through a crossover switch near a highway overpass, and the remains of the wheel were caught in the flange guide rail of the switch. The impact derailed the axle of the cracked wheel and ripped the guide rail from the crossties, pushing it into a vertical position, where it punctured the floor of the car and lifted the bogie off the rails. This was

the first time the engineer had any indication of a problem. He reported he felt a “pull” on the back of the train and looked back to see the derailment unfolding.

As the train went through the second crossover switch, the derailed bogies caused the switch points to realign. This sent the trailing bogie of car three onto a parallel track, and the body of the car hit the concrete piers of the 300-ton roadway bridge as it passed underneath. The 120 mph impact destroyed the bridge supports, completely collapsing the structure. As the trainset derailed and separated, emergency brakes on each car were automatically activated.

The lead power car stayed on the rails and came to a stop two miles down the line from the accident site. The first three coaches derailed but remained upright and came to a stop about 100 feet beyond the bridge. Coach four was moving fast enough to go under and clear the bridge before it collapsed. Car four was separated from the first three, derailed, and rolled over into trees along the ROW. Adding to the tragedy of the accident, two DB employees working along the ROW were crushed and killed by the car as it rolled over.

The fifth coach was actually severed by the collapsed bridge. The front half traveled about 300 feet past the bridge, while the rear half was crushed under the weight of the overpass. Car six was directly under the bridge at the time of the collapse and was completely flattened. Cars seven through 11 were all destroyed under or up against the remains of the bridge. The twelfth and final car of the train did not impact the bridge but was partially crushed by the rear power car, which, itself, received minimal damage. The train had a capacity of 743 passengers but was carrying only 287 at the time of the accident. The aftermath of the incident is shown in Figure 13.

Figure 13. The Eschede Incident Scene

A week after the incident, the final death toll reached 101, including the two DB employees who were working along the ROW. Eighty-eight passengers and crew were also injured in

the incident. The official accident report as well as research reports that analyzed available data on the incident concluded that the root cause was a catastrophic failure of a wheel tire. The application of the wheel technology was questioned and openly criticized prior to the incident, and some officials felt that the testing of the materials prior to the installation was inadequate.

The severity of the incident was exacerbated by the environment in which the wheel failure occurred and by the procedural reactions of the passengers and crew. Had the wheel failed along a section of ROW that did not include crossover switches (turnouts), the train would most likely have remained linear and upright. The location of the highway bridge pier between the tracks was the most significant contributing cause, since it not only presented an obstruction for the derailed cars but led to the failure and collapse of the bridge, which directly caused most of the fatalities, injuries, and damage.

DB company policies prohibited the conductor or any other train crew member from applying the train's emergency brakes until a visual inspection of the situation was performed. This delay provided the time for the accident chain to play out and the derailed train to collide with the bridge pier. The passenger who first noticed the broken guardrail puncturing the floor of the carriage was apparently also not informed through announcements or safety cards to apply the brakes in the event of an emergency.

As in any transportation incident of this magnitude, lessons are learned, policies are changed, and practices from engineering to operations are evaluated and modified. DB assessed a number of its procedures, including the testing and inspection of materials, track components, and rolling stock, as well as response directives for crew and passengers. Many other HSR operators and non-HSR passenger rail systems around the world also analyzed the pre- and post-incident factors of the Eschede incident and modified their policies and practices.

In the United States, officials from the Federal Highway Administration and several state departments of transportation are investigating ways to design and build new highway overpasses that cross rail lines, rivers, and other roads to eliminate mid-span piers located in the flow of traffic. This will improve safety and eliminate potential obstructions that could cause or escalate accidents. Other countries are conducting similar efforts to create safer crossings, as well as specifically relocating rail crossovers, where possible, away from existing bridge piers or other potential ROW obstructions.

DB and other railroad operators in Europe also began to look at how the design and construction of rolling stock contributed to the amount and severity of injuries and fatalities and hampered egress and access efforts by passengers and emergency responders. In the United States, railroads began to improve responder training and develop new standards for passenger-car construction, including the design, labeling, and operation of emergency-exit windows and doors.

2. Chinese High-Speed Railway – July 2011

Worries about the haste with which China is building its HSR system peaked in July 2011, when one high-speed train carrying 558 people plowed into the back of another train carrying 1,072 people on a viaduct near Wenzhou in southeastern China. Forty people were killed and more than 200 were injured, 12 of whom remained in critical condition for several days following the collision.

A severe thunder and lightning storm had caused signal problems that evening, and train engineers were being directed by control-center dispatchers to proceed with caution at speeds below 12 mph if they came across red signals. This procedure was intended to allow any engineer to safely stop the train if any other trains or obstructions were seen on the tracks ahead. The engineer of the lead train proceeded as directed, but the ATP feature shut down his train after he passed a red signal. At that point, the compromised track-detection circuitry failed to identify the train in the block and established a green signal for the train behind it.

After seven minutes of trying to override the ATP system, the lead-train engineer was able to restart his train. Unfortunately, the train behind it had a green signal, so it was never directed to switch to visual running procedure and went past the signal at normal operating speed. Shortly after exiting a tunnel, the trailing train quickly came upon the lead train, which was just starting to move, and slammed into the rear end of it at 62 mph.

The last car of the lead train (a coach car with an engineer's cab) and the next three cars derailed and were knocked off the viaduct by the collision. Three of the cars fell 50 feet to the ground below, and one car ended up vertically—one end was on the ground and the other was leaning against the top of the viaduct. The lead coach/engineer's-cab car and the first car of the other train also derailed but remained on the viaduct. The first car was demolished by the impact, and the second car rode up on top of it. Although unconfirmed, it is speculated that most of the deceased were in the lead train cars that fell off the viaduct and the first car of the trailing train. Neither trainset design used articulated cars/bogies, but except for the six cars that derailed, the remainder of both trains stayed upright and linear with the track, the vast majority staying on the track. The aftermath of the collision is shown in Figure 14.

Figure 14. The Aftermath of the Wenzhou Collision

While there were many questions regarding the immediate and long-term responses of the MOR and other Chinese government agencies and officials to the incident, the most troubling issue was the fact that rescue operations were ordered to stop less than 24 hours after the collision. The cars that fell off the viaduct were broken up on-site by heavy machinery and buried prior to any investigative actions. MOR claimed that the cars were quickly scrapped and buried to keep sensitive national technology from falling into the wrong hands. Others speculated that the claims by Kawasaki and other smaller component manufacturers regarding patent theft were the driving factor.

The lack of credible information regarding the incident or the post-incident response and investigations makes it difficult to identify lessons learned. The apparent cause seems to have been a poorly designed and/or inadequately tested and evaluated signal- and train control system that failed and did not communicate the presence of a train within a block to other trains in the area. In addition, similar to the ICE Eschede disaster, the severity of the incident was exacerbated by the environment in which the equipment failure occurred. The greatest number of fatalities and the most injuries and damage were caused by the car falling off the viaduct.

3. RENFE – March 2002

Figure 15. RENFE Collision in Torredembarra

The only significant incident on RENFE's entire HSR network occurred in March 2002 in Torredembarra, about 50 miles southeast of Barcelona. A Euromed train traveling at about 65 mph through the station to Barcelona collided with a commuter train. The commuter train had left the platform and was crossing over onto another track when it was struck by the Euromed traveling in the same direction. The commuter train was carrying approximately 350 passengers, and 290 were on the Euromed train. Two people were killed in the collision; which trains they were on is unclear. In addition, 142 people were injured, some of them seriously. Many were trapped in the wreckage, requiring extensive extrication efforts by the local emergency services. While there are no available data on how many injuries occurred on each train, eyewitness accounts referenced in several media stories stated that the majority were on the Euromed train. The aftermath of the incident is shown in Figure 15.

RENFE promised an immediate investigation into the cause of the accident. Unfortunately, other than the obvious cause—two trains on the same track at the same time—no further information from RENFE or the Spanish government was available. Spain is one of several countries that do not release information on rail-accident investigations.

4. Trenitalia – January 1997

The most tragic incident involving Trenitalia HSR service occurred in January 1997, when a train left the rails about 30 minutes into its run from Milan to Rome. As it rounded a curve at approximately 120 mph, the lead car of the train derailed and ran into a catenary support pole. What was originally attributed to excessive speed or a foreign object on the tracks was determined, following an investigation, to be caused by a ruptured universal joint connecting the traction motors to the wheels. Eight people were killed in the accident: two engineers, three railroad police officers, a restaurant-car worker, and two passengers. The nine-car train, which had a capacity of 480, was carrying only 150 passengers at that point in the trip. Twenty-nine people were hospitalized with injuries, and many more were treated for less-serious injuries.

5. TGV – September 1988

The first major accident on the TGV happened in September 1988 at a grade crossing in Voiron, when a 10-car train running from Grenoble to Paris hit a heavy-duty flatbed truck carrying a 100-ton electrical load at 68 mph. The truck, which was not permitted to use the crossing, became stranded or stuck on the tracks at the crossing. The lead power car derailed, and debris from the truck and its load ripped open the first coach, killing one passenger and injuring 60 others. The impact also killed the engineer, and the collision became a seminal event in the crashworthiness design and testing process of future rolling stock. New versions included improved crash protection for the engineer and crash-energy-absorption zones in the power cars and the front of the first trailing coaches.

6. Trenitalia – March 1998

In March 1998, an HSR train collided with a regional passenger train in Castello, near Florence, and derailed as it was tilted on a curve. Information on the incident, which is listed in the EU rail-accident-investigation database, is very limited. At the time of the incident, the cause was thought to be a signal failure. Twenty-seven people were injured in the accident, and one person on the regional train was killed.

7. TGV – December 2007

In December 2007, a truck driver was killed when a trainset traveling from Paris to Geneva hit his truck at 62 mph and derailed. The truck was stuck in the grade crossing when it could not pass beneath the overhead catenary. The truck driver had left the cab but was killed by the impact before he could safely leave the ROW. The engineer suffered serious injuries, and conflicting reports from international news services identified 24 to 34 minor injuries to passengers on the train. The other 150 or 160 passengers were safely evacuated. The damage to the lead power car was extensive enough for SNCF to scrap the unit.

8. ICE – April 2006

In Thun, Switzerland, an engineer hostling two light locomotives was unfamiliar with the revised layout of the terminal and did not see a shunting signal directing him to stop. Passing the signal immediately activated his locomotive's emergency brakes, but at that point the lead engine was fouling the track of an approaching ICE 1 trainset, activating that train's emergency brakes as well. The brake application slowed the ICE train from 45 mph to 35 mph by the time of the head-on collision, but the ICE engineer and 30 passengers on-board suffered minor injuries. The engineer of the light locomotives safely jumped from the units before the collision. All of the involved equipment suffered major damage and required extensive rebuilding.

9. TGV – December 1992

In December 1992, a 10-car trainset travelling from Annecy to Paris derailed as it passed through Macon-Loche station at 168 mph. A flat wheel, resulting from a previous emergency stop, caused one of the trainset's bogies to come off the rail while going through a switch

at the entrance to the station. The train stayed upright and linear, and no one on board was injured. The derailed wheel, moving at high speeds, launched a lot of ballast (stone) in the station, injuring 27 passengers who were waiting on the platform for another train. This was the first incident to occur on one of the LGV (dedicated high-speed) lines.

Safety Improvements

Minimizing the Impact of Derailments

Analysis of the incident data revealed that the most frequent cause of accidents in HSR operations has been foreign (non-railroad) obstructions on the ROW, with vehicular grade crossings topping the list. The remaining causes were most often related to equipment malfunctions attributed to flaws in the engineering and/or construction phases of developing rolling stock or infrastructure. As mentioned earlier, the design of a trainset's connections between cars plays the most significant role in the severity of an incident. In short, the more a train—by design—stays linear and upright in a collision or derailment, the better the life-safety conditions.

Since the day when the first steel wheel rolled down a steel rail, railroaders and engineering experts have been trying to figure out how to improve efficiency by reducing wheel-on-rail friction. One early, out-of-the-box approach was to reduce the number of wheels/axles under each car of the train while still supporting and distributing the weight of the cars' live load. Some early steam-powered streamlined trains and first-generation internal-combustion trainsets used partial or complete articulation. By having two carriages or passenger-car bodies share a wheelset, the total number of wheels per train could be reduced, thereby reducing the overall amount of wheel-on-rail friction.

Second-generation HSR trainsets have reintroduced this concept. An unintended consequence of articulation, demonstrated in several incidents at various speeds, is that the trains stay linear and upright. Since the cars do not accordion (fold onto one another), telescope into one another, or roll over, the number and severity of traumatic injuries are significantly reduced in derailments and collisions.

Even trainsets that do not share wheelsets or bogies but employ semi-permanent connections rather than knuckle-type couplers are more apt to stay upright and linear in an incident. Aside from the Eschede accident and the Wenzhou collision, where infrastructure design played a critical role, trainsets in almost every other HSR derailment, collision, or terrorist attack have stayed upright and in line. The vast majority of commuter and intercity passenger trains (which use knuckle-type couplers) that have been involved in a derailment or collision in the past several decades have had multiple cars (and locomotives in several cases) leaving the tracks and ending up in various states of destruction.

A modern case of unintended engineering consequences is that of the Shinkansen Series 200 trainset involved in a 2004 Joetsu derailment, where 11 of the train's 40 axles derailed during an earthquake. The Series 200 truck, or wheelset, had a component inside the wheel span that protruded downward and inadvertently pinched the rail between it and the inside rail surface. This feature was credited with playing a significant role in maintaining

the train's position and posture in the derailment. Aside from the trailing power car, which deviated into a drainage trough in the slab track and slightly lifted after the rails completely broke at a joint, the train remained upright and in line.

Following this incident, which resulted in no injuries or fatalities, JR East conducted a series of tests on possible rolling-stock and ROW improvements that were intentionally designed to prevent catastrophic derailments, specifically in the event of an earthquake. JR East's research and analysis included a systemwide damage assessment and an assessment specifically focused on the events that occurred in the derailment and yielded two very important conclusions. First, damage to structures (track) and the settlement of structures were both negligible and were not considered to be a cause of the derailment. Second, based on the results of simulations (modeling), the incident was attributed to the railcars oscillating below the center of gravity after receiving large seismic waves, resulting in a rocking derailment.

This comprehensive research effort spawned four concepts for further reducing the impact of seismic activity. The first, which was introduced in 2006, was the development and installation of a railcar guide mechanism. The L-shaped guide is cast as a single unit and mounted with four bolts to the underside of the axle (journal) box. The purpose of the guide is to significantly limit the lateral deviation of the wheelsets in the trackway during a derailment. By being kept in line with the track, the train will be less prone to significantly damage the ROW; strike tunnel walls; fall off bridges or viaducts (even though guardrails are also currently used in these environments); or foul adjacent tracks. This measure, which could ultimately prevent collisions, was developed, tested, and shown to be effective in slab-track environments. A separate railcar guide is being developed by JR Central for ballasted-track environments.

The next two concepts focused on increasing the probability of maintaining a track's integrity. First, the glued insulated joint (IJ) used to connect rail sections was improved, possibly to create expansion joints in the rails. An IJ broke in the Joetsu derailment, leading to the significant deviation of the trailing power car from the track. A new glued IJ was developed and introduced in 2007 that prevents the rail from breaking even when it is subjected to the impact from derailed wheels outfitted with the L-shaped railcar guide. The second improvement was the development of a rail anti-toppling device. This concept was developed for slab-track applications and uses large, inverted L-shaped brackets to grasp the foot of the rail and hold it in place despite the lateral forces placed on it during a derailment. A ballasted-track version of the anti-toppling device is also under development by JR Central.

The fourth outcome of the research focused on shortening the time required to apply emergency brakes when overhead power is cut off. The original system included a feature that shut down power in the overhead catenary in the event of an earthquake and an on-board device that applied a train's emergency brakes when this power shutoff was detected. The research yielded a new power-detection device that significantly (relative to the situation) shortens the time between power cutoff and emergency-brake application.

While the integrity of the viaduct in the Joetsu derailment was not compromised by the earthquake, many other Shinkansen line bridge and viaduct piers and abutments suffered significant damage. In response, JR East developed processes to measurably improve structural strength, including the installation of reinforcing steel plates around piers and columns.

Reducing Damage from Collisions

The concept of crashworthiness was reevaluated following the September 1988 crash of a TGV trainset into a low-boy trailer carrying a large piece of equipment at a grade crossing. The train did not derail, but the engineer perished in the collision. Much of the impact was absorbed in the engineer's cab, which completely collapsed on impact. The incident investigation also revealed that about 10% of the crash energy had been absorbed in deformations of the first trailer. While this incident occurred when the train was moving at only 65 mph, it was concluded that energy-absorption patterns, particularly in the first trailer, in higher-speed incidents could result in serious injuries to crew and passengers.

The first step taken to address crashworthiness was improving the integrity of the engineer's cab. While the improvements were modeled and tested prior to installation to ensure the desired results, the proof has been unfortunately demonstrated on several Lines Classiques grade-crossing collisions since then, with various-sized trucks and loads, where the engineers have suffered injuries but survived.

The coupling between the power car and trailers was also reviewed in the post-incident research. While the TGV system still employs screw-link couplers and buffers, the buffers have been modified to include fuses that activate under crash loads, effectively folding the buffer and absorbing energy. Improvements were also made to the car ends to prevent the power car from climbing onto the first trailer car. The Scharfenberg couplers in the power-car noses were redesigned to collapse in multiple-unit operations when placed under sudden loads characteristic of collisions. This will allow two facing power cars to make firm contact and, it is hoped, prevent telescoping.

Other European and Asian efforts to analyze crashworthiness and rolling-stock integrity and strength focus on the balance between a safe carriage and the use of the lightest possible materials to maximize weight reduction. Some ICE- and TGV-based trainsets, while not derailing, have experienced sizable car-body gashes or more significant failures in collisions, increasing the risk of serious injuries to passengers and crew. In the United States, all revenue equipment must be built to comply with FRA crashworthiness standards, which are typically much more stringent than those in other countries. While this makes it impossible for Amtrak or other U.S. passenger-rail systems to buy off-the-shelf trainsets from European or Asian suppliers, it ultimately makes the carriage-car bodies stronger and more resilient and thus safer in derailments and collisions.

Right-of-Way Protection

TGV and other systems have made advancements in isolating their ROWs, particularly on LGV lines, and installing systems to identify intrusions. All LGV lines are grade-separated

and fenced off, restricting access by pedestrians and animals. Sensors have also been installed on overhead bridges and tunnels to detect falling objects and other accidental or intentional perimeter breaches. The sensors communicate an alarm to control centers and trains, notifying them of an intrusion. Procedures dictate measures to be taken during such alarms to avoid collisions and allow for investigations of the situation without completely shutting down service in most cases. These steps to prevent and/or detect accidental or intentional intrusion on the ROW not only reduce accidents but also enhance security measures, particularly in areas of critical vulnerability.

Outside the TGV LGV environment and the China HSR ROW, which were designed and built as grade-separated systems, grade-crossing reduction or complete elimination is the most significant step HSR operators can take to reduce collision hazards. But, as seen on several systems, the potential for vehicles, equipment, pedestrians, and livestock to venture onto the ROW, outside of public crossings, must also be addressed.

Train Control/Signaling/Communications

Train control and signaling technology continues to evolve, particularly as train speeds increase, rendering human reaction times to line-of-sight, wayside block signals far too slow to prevent incidents. As seen in the Wenzhou collision, however, one of the most important characteristics of any system is the need to have a fail-safe mode in the event of power disruptions or failures or other system malfunctions.

Signal and train control systems need to be not only more reliable and resilient, but fail-safe in sabotage situations as well. In one case, the theft of copper wire from a system caused a malfunction and resulted in a collision—fortunately, only a slow-speed collision. Such design flaws could be exploited for more-sinister acts than material theft. Short service disruptions, no matter how frequent, are always preferable to the alternatives when a system fails to stop operations.

Conclusion

The advent and growth of passenger HSR has introduced and/or refined a wide array of safety features, only some of which have been discussed in this report. Incidents such as collisions and derailments have consistently demonstrated the vast array of inherent characteristics and design features that significantly reduce the number of injuries and fatalities, as well as damage, particularly in comparison with other passenger-train operations such as densely crowded commuter trains.

The lessons learned from the exemplary HSR safety record thus far should form the foundation for future developments in infrastructure design, equipment, and system technology, as well as operational practices and procedures. Extrapolating the lessons learned from safety inquiries should lead security planners to focus on reducing vulnerabilities.

The record of incidents in Europe and Asia clearly reveals that high numbers of injuries and deaths occur when HSR trains collide with other trains or massive objects, and that

specific locations or design features along the infrastructure put rail passengers at greater risk of catastrophic consequences in the event of an incident.

Particularly vulnerable areas include:

- Grade crossings that offer easy access to terrorists wanting to derail trains
- Stretches of track with compromised visibility (e.g., adjacent to tunnels or significant curves)
- HSR stations with high volumes of other rail traffic
- Signaling and communications systems that could be subject to cyber attacks
- Elevated viaducts
- Tunnels
- Sections of ROW adjacent to major structures (e.g., overpasses) that could be comprised

These vulnerabilities are not unique to HSR. Intercity, commuter, and heavy-rail trains all operate in the same or similar environments. In the past 50 years, high-speed passenger rail has proven that faster trains can not only be as safe as traditional trains, but in many cases, they can be safer. This is a benefit not only to HSR systems but to all passenger-rail operators, particularly those who learn from and borrow from HSR experiences, and ultimately the countries and communities they serve. The HSR safety record in Europe and Asia clearly indicates that formulating a strategy for securing HSR in the United States separate and apart from the rest of the passenger, and even freight-rail, network is not warranted solely because the trains go faster. The United States simply has the opportunity to apply lessons learned to the design and construction of a new system.

APPENDIX A:
HSR INCIDENTS ON SELECTED SYSTEMS IN EUROPE, ASIA, AND THE UNITED STATES

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
April 1966	Shinkansen Tokaido	0-Series	Unknown	A conductor noticed the last car was shaking; a loud crash and sparks from the undercarriage followed. Upon notification, the engineer quickly stopped the train. On-site inspection revealed that an axle on the rear car had cracked.	Faulty grinding of a rear-car axle during the manufacturing process.	Rigorous axle inspections were instituted immediately following the incident, using ultrasound and fluorescence technologies. No similar incidents have occurred with Shinkansen equipment.	0	0
February 1973	Shinkansen Out of service	0-Series	Braking	A train departing the yard skidded through a stop signal, entering and fouling the main line as a revenue train was approaching. The driver and dispatcher tried to back the train off the main line, causing a complete derailment.	Wear-prevention oil on yard departure track caused the train to skid onto the mainline, breaking the switch points.	The ATC cab signal system worked as intended. The approaching revenue train was far enough away to stop safely, preventing a catastrophic incident.	0	0
September 1974	Shinkansen Tokaido	0-Series	18 mph	The cab signal suddenly displayed zero, and the brakes were automatically applied. After the train came to a complete stop, the cab signal indicated 30 (proceed at 30 kmh). As the driver proceeded slowly, he noticed a closed switch point, stopped the train, and immediately reported it.	An ATC system malfunction was attributed to a high-power electrical device adjacent to an ATC ground controller, which induced a current in the ATC circuit at the same frequency as the 30 cab signal indication.	Steps were taken system-wide to physically separate all power equipment and ATC devices.	0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
September 1988	TGV Sud-Est LC	PSE	68 mph	A 10-car trainset hit a heavy-duty flatbed truck at a grade crossing. The lead powercar derailed, and debris from the truck and its 100-ton electrical load ripped open the first coach.	The truck, which was not permitted to use the crossing, became stranded or stuck on the tracks.	The collision became a seminal event in the crash-worthiness design and testing process of future rolling stock, leading to improved crash protection for the engineer and crash energy-absorption zones in the powercars and the front of the first trailing coaches.	60	2 (engi-neer and passen-ger)
January 1991	TGV Sud-Est LC	PSE	37 mph	The train experienced a brake failure while in the depot and entered the line as a runaway. Lacking any passengers or on-board crew, the CTC dispatcher diverted the train into a siding, where it collided with the car-loading ramp. The lead power unit and the first two cars were extensively damaged.	Brake failure.		0	0
December 1992	TGV Sud-Est LC	PSE	168 mph	The 10-car trainset derailed as it passed through a station. The train stayed upright and linear, and no one on board was injured. However, the derailed wheel, moving at high speeds, launched a lot of ballast (stone) in the station, injuring 27 passengers waiting on the platform for another train. This was the first incident to occur on one of the LGV (dedicated high-speed) lines.	A flat wheel due to a previous emergency stop event caused one of the trainset's bogies to come off the rail while going through a switch at the entrance to the station.		27	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
December 1992	TGV Nord	Reseau	182 mph	The last four coaches and the trailing powercar of a 10-car trainset carrying 200 passengers derailed after crossing what appeared to be a 10-foot by 20-foot mud puddle. Despite the back half of the train derailing, the trainset remained upright and in line with the track due to the design of the shared bogies in the trainset and the set's relative stiffness. At 182 mph, it was the world's fastest derailment.	Unsupported track traversing a 23-foot-long, 5-foot-deep sinkhole.	The track was carefully inspected to prevent future events.	2	0
September 1995	TGV Paris-Brest LC	Atlantique	87 mph	A 12-car trainset hit an unoccupied flatbed truck carrying farm equipment at a grade crossing. The train did not derail and after an immediate emergency-brake application came to a stop about a mile from the point of impact. The tractor-trailer was totaled. The train's lead powercar, overhead catenary support masts, and the road crossing gates were damaged.	An unoccupied truck was stuck on the tracks at a grade crossing after coming out of a tightly banked curve.		2	0
December 1995	Shinkansen Tokaido	0-Series	Exiting the station	A passenger was caught in the train door and died from injuries he sustained while being dragged down the platform.		Sensors were installed on train-car doors to prevent the doors from closing with an obstruction present.	0	1
February 1996	Eurostar Channel Tunnel	Eurostar x2	Stopped	Two trains stalled inside the tunnel, stranding more than 1,000 passengers in the darkness for several hours.	Electronic failures caused by the buildup of ice, snow, and salt on the trains, tracks, and catenary.		0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
January 1997	Trenitalia-Piacenza	ETR-460	>100 mph	As the train rounded a curve, the lead car derailed and ran into a catenary support pole. The accident killed eight people: two engineers, three railroad police officers, a restaurant-car worker, and two passengers. The nine-car train had a capacity of 480 passengers but was only carrying 150 at that point in the trip. Twenty-nine people were hospitalized with injuries, and many more were treated for less serious injuries.	A ruptured universal joint connecting the traction motors to the wheels.		29	8
May 1997	SJ-2000 Slätte	X-2000	118 mph	Train derailment.	Axle failure.		0	0
September 1997	TGV Paris-Dunkirk LC	Reseau	81 mph	The train collided with an asphalt paving machine that got stuck on the tracks. The lead powercar separated from the trainset and spun around, coming to rest alongside the remainder of the trainset's cars on its side and facing backwards. Even though the lead power car was destroyed, the engineer suffered only minor injuries. Four of the train's eight passenger cars derailed, and two of those cars left the track. Aside from the power car, the remainder of the trainset remained upright and, for the most part, linear.	Truck stuck on the tracks at a grade crossing.	As unfortunate as this incident was, the outcome was a testament to the crashworthiness improvements made following a fatal 1988 grade-crossing collision.	7	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
October 1997	TGV Sud-Est	PSE	Unknown	The engine compartment of the 10-car trainset's lead power car caught fire. Following an emergency-stop procedure, the passengers and crew relocated to the rear cars of the trainset. The local fire brigade confined the fire to the lead power car, and the 621 passengers were transferred to another trainset.			0	0
November 1997	TGV Paris-Brest LC	Atlantique	87 mph	The 12-car trainset hit a tractor trailer at a grade crossing. The driver of the disabled truck was able to escape unharmed. The front nose of the lead power car was completely crushed, one bogie or wheelset in the train derailed, and the overhead catenary, catenary supports, and the track were damaged.	Disabled truck on the tracks at a grade crossing.		6	0
March 1998	Trenitalia Castello	Unknown	Unknown	A train collided with a regional passenger train and derailed as it was tilted on a curve. Twenty-seven people were injured in the accident, and one person on the regional train was killed.	At the time of the incident the cause was thought to be a signal failure.		27	1
May 1998	Thalys Hoeven	PBLA	Unknown	A Thalys train hit a truck at an unprotected grade crossing near Hoeven in the Netherlands. The truck driver was killed and six passengers were slightly injured as the truck was struck and slid along the train. The first two coaches were damaged so severely that they both had to be scrapped.	Unprotected grade crossing.		6	1 (the truck driver)

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
June 1998	ICE Eschede	ICE 1	125 mph	The train traveling at 125 mph derailed as it was passing under a highway overpass. One of the derailing cars knocked out the overpass supports, collapsing the concrete structure on several of the passenger cars.	A defective wheel design caused a wheel to crack apart. The remains of the wheel were caught in the flange guide rail of a switch, derailing cars.	All ICE 1 trainsets were immediately taken out of revenue service and recalled to the yards for inspection.	87	101
June 1998	SJ-2000 Kumla-Hallsberg	X-2000	87 mph	Train derailment.	Axle journal failure.		0	0
November 1998	TGV Paris-Brest LC	Atlantique	75 mph	The train collided with a tractor-trailer at a grade crossing. The truck driver escaped injury. The front of the lead power car was significantly damaged, but all passengers and crew were uninjured.	Truck that got stuck on the track at a grade crossing while attempting to turn around.		0	0
June 1999	Shinkansen Sanyo	0-Series	125 mph	A train was struck by falling concrete as it traveled through the Fukuoka tunnel between Kokura and Hakata. The concrete tore a 50-foot by 3-foot gash in the roof of a coach and damaged the pantographs of two other cars.	Improper tunnel construction practices.	Thorough tunnel inspections were conducted on the line to identify and remediate any other similar defects.	0	0
October 1999	Shinkansen Sanyo	Infrastructure	N/A	A 10-foot by 1-foot by 6-inch slab of concrete fell from the wall of the Kitakyushu tunnel. While causing significant service delays, the incident did not damage any rolling stock or cause any injuries.	Improper tunnel construction practices.	Thorough tunnel inspections were conducted on the line to identify and remediate any other similar defects.	0	0
March 2000	ICE Berlin	ICE T	Slow	A new trainset derailed as it approached a maintenance shop. The train was out of service at the time, carrying no passengers, and moving at a slow speed. After the train was re-railed with the aid of a crane, it derailed again once it started moving.		Immediately following the incident, the other 11 new trainsets were pulled from service for inspection and possible repair.	0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
June 2000	Eurostar LGV Nord	Eurostar	180 mph	A train derailed in northern France. Before the derailment the engineer detected a vibration and slowed the train to 125 mph and then resumed speed when nothing else was identified. Shortly thereafter a link on the lead power car's rear bogie separated from the frame and caused a complete failure of the transmission assembly. The partially derailed train remained upright and came to a stop in just under a mile. The trainset and right-of-way were only slightly damaged. The articulated design of the trainset was attributed with keeping the train in line and upright.	The failure of the bogie and the emergency stop caused the damaged bogie to derail along with the adjacent bogie on the first coach and the back bogie of the trailing power car.		14	0
January 2001	TGV Paris-Brest LC	Atlantique	75 mph	The engineer saw an obstruction on the tracks and applied an emergency stop, slowing the train to 75 mph at impact. The lead power car of the trainset experienced a minor derailment, but the rest of the train remained on the rails. There were no injuries to passengers or crew.	A mudslide that resulted from a winter storm spread across the tracks.		0	0
February 2001	SJ-2000 Lindekullen	X-2000	87 mph	Train derailment.	Axle failure.		0	0
September 2001	ICE Hof	ICE TD	Stopped	A trainset fell off a work platform in a maintenance yard and was damaged so extensively that it had to be scrapped.			0	0
October 2001	SJ-2000 Gnesta	X-2000	112 mph	Train derailment.	Axle journal failure.		0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
October 2001	TGV Paris-Hendaye LC	Atlantique	80 mph	A section of rail fractured underneath the train's lead powercar. The entire trainset derailed, but only the trailing power car rolled over on its side. In addition to the rolled-over power car and derailed trainset, significant damage was done to the track, overhead catenary system, and several support masts.	The rollover was attributed to the fact that unlike the articulated coaches that make up the majority of the train, the power cars do not share wheelsets or bogies; instead they each have two bogies.		5	0
November 2001	Offenbach	ICE 1	Stopped	The lead power car of the trainset in revenue service stopped at a station and caught fire. The train was safely evacuated at the station, and the fire was contained to the one power car. Damage to the unit, however, was so severe that it was scrapped.			0	0
December 2001	Shinkansen Sanyo	Series 200	125 mph	A passenger used the emergency release handle to open the door of a moving train and jumped to his death.		Trainsets were eventually modified to prevent door levels from operating while a train is in motion.	0	1
March 2002	RENFE Torre-dembarra	Euromed	65 mph	As the train was traveling through a station, it collided with a commuter train traveling in the same direction. The commuter train had left the platform and was crossing over onto another track. The commuter train was carrying approximately 350 passengers, and 290 were on board the Euromed train.	Officials promised a complete investigation, but no information was made publicly available.		142	2
January 2003	TGV Paris-Dunkirk LC	Atlantique	Unknown	A train struck a truck at a grade crossing. The front power car was severely damaged, one of the power car's bogies derailed, and the engineer received minor injuries.	Truck on tracks at grade crossing.		1	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
January 2003	VR Pendolino Perniossa	Sm3	Unknown	A door was ripped off the train as it was traveling at speed through a tunnel. The pressure change in the tunnel dislodged the door, and the speed ripped it from its mounts. The train was stopped and inspected and authorized for restricted-speed movement to the next station, where it was offloaded and taken out of service.	Improperly locked door.	Trainset speed through tunnels was restricted to 75mph until the door settings on all of the other trainsets were checked for possible malfunctions.	0	0
July 2003	VR Pendolino Karjaa	Sm3	<30 mph	The trainset derailed just outside a station. A faulty turnout could not be reset or overridden by the control center and continued to display a red signal. Mechanics were dispatched to the scene to inspect and, if needed, fix the turnout. After several positive tests of the turn-out's switch blades or switch points, the control center authorized the train to proceed through the red signal and switch. Moving at less than 30 mph, the train made it safely through the turnout's points but derailed the first three cars of the six-car train, as well as the leading bogie of the fourth car, as it went over the turnout's frog. The trainset and the track were significantly damaged.	Both the mechanics on site and the control-center personnel were unfamiliar with the design of the turnout and were not aware that it also had a "moveable frog," commonly used in high-speed crossover switches.		0	0
January 2004	ICE Leipzig	ICE T	Stopped	A fire occurred on a parked out-of-service trainset. There were no injuries, but two of the cars in the trainset were totaled, and the rest of the units were put into reserve to be used as spares.			0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
April 2004	ICE Istein	ICE 3	50 mph	A train struck a tractor on the tracks, derailing the lead power car and the first coach. The tractor driver was seriously injured, while the engineer and one passenger received minor injuries.	A farm tractor working in vineyard fields along the ROW slid down an embankment and onto the tracks.		3	0
October 2004	Shinkansen Joetsu	Series 200	130 mph	A 10-car train derailed on a 45-foot-high elevated section of the ROW.	The October 23, 2004 Niigata Chuetsu earthquake. The train was only about six miles from the epicenter.	A number of engineering measures not specifically related to crash/derailment prevention were found to have helped prevent passenger injuries. This led to the reengineering of train-sets to help minimize the potential impact of derailments.	0	0
October 2004	Amtrak Acela New Haven, CT	Acela	Slow	The train was performing a slow-speed reverse move when it went through a red signal and its trailing power car and coach derailed. The train came to rest between two retaining walls but also knocked down a catenary support pole, which leaned up against the train-set, while the overhead wire was lying on the train's roof. The rest of the train remained on the track, and the entire trainset stayed upright and liner. The train was carrying 76 passenger and six crew members at the time of the incident. Two of the passengers received minor injuries.	Human error.		2 (minor)	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
September 2005	Amtrak Acela Waterford, CT	Acela	70 mph	The train collided with an automobile at a grade crossing. Eyewitness accounts and post-incident testing confirmed that the crossing gates were working properly at the time of the accident. The front end of the lead powercar was slightly damaged, but the entire trainset, including the lead power car, remained on the rails. The automobile was totaled and its three occupants were killed immediately. None of the 130 passengers or crew on board the train was injured.	A car that drove or slid underneath the gates at a grade crossing.		0	3 (occu-pants of the motor vehicle)
February 2006	SJ-2000 Knivsta-Mybracken	X-2000	>87 mph	Train derailment.	Axle journal failure.		0	0
April 2006	ICE Riedbahn	ICE 1	Unknown	The train collided with an automobile, severely damaging the lead power car. No one on the train was harmed except for the engineer, who received minor injuries.	Automobile on tracks at grade crossing.		1	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
April 2006	ICE Thun, CH	ICE 1	35 mph	An engineer hostling two locomotives was unfamiliar with the revised layout of the terminal and did not see a shunting signal directing him to stop. Passing the signal immediately activated his locomotive's emergency brakes, but at that point the lead engine was fouling the track of an approaching ICE 1 trainset, activating that train's emergency brakes as well. The brake application slowed the ICE 1 train from 45 mph to 35 mph by the time of the head-on collision, but the ICE engineer and 30 passengers on board suffered minor injuries. The engineer of the locomotives safely jumped from the units before the collision.	Human operating error.		31	0
July 2007	SJ-2000 Gnesta	X-2000	112 mph	As the train was traveling through a station, it derailed on a left-hand curve. The train remained upright and linear as it came to a stop. The stiff frame of the bogie, which rode along the top of the rails, reduced the transmission of vibration from the wheels going over the ties and was credited with keeping the train on the track bed.	The second axle of the lead bogie on the lead car derailed but remained intact. Subsequently, the other axle of the bogie also derailed.		0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
December 2007	TGV Sud-Est LC	PSE	62 mph	A train hit a truck at a grade crossing and derailed. The truck driver had left the cab but was killed by the impact before he could safely leave the ROW. The engineer suffered serious injuries, and conflicting reports from international news services identified 24 to 34 minor injuries to passengers on the train. The other 150 or 160 passengers were safely evacuated. Damage to the lead power car was extensive.	The truck could not pass beneath the overhead catenary.		24	1 (the truck driver)
March 2008	Shinkansen Tokaido	Series 200	125 mph	A passenger used the emergency release handle to open the door of a moving train and jumped to his death.		Trainsets were modified to prevent door levels from operating while a train is in motion.	0	1
March 2008	ICE Brühl	ICE T	Unknown	A train collided with a large tree fouling the tracks. The front end and cab of the lead power car were seriously damaged. The driver suffered severe injuries, but there were no other injuries.	A tree was toppled onto the tracks by cyclone with winds in excess of 100 mph.		1	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
April 2008	ICE Landrucken Tunnel	ICE 1	125 mph	A train carrying approximately 150 passengers ran into a flock of about 40 sheep as it entered the 7-mile-long Landrucken Tunnel. While the vast majority of the trainset's cars derailed, all stayed upright and in line. The derailment caused damage to the tunnel lining, but no significant structural damage, and ripped up much of the track before coming to a stop a half mile into the tunnel. The engineer and three passengers suffered serious injuries (broken bones and serious lacerations) and needed to be transported to local hospitals. The rest of the injuries were treated at the scene, and most of the passengers self-evacuate before rescuers arrived.	Sheep wandering on track.	Several questions were investigated regarding why there was no fencing or barriers preventing animals and pedestrians from entering the tunnel and why information reported by the engineer of a previous train regarding sheep in the area was not shared.	19	0
April 2008	Shinkansen Tokaido	Series 200	125 mph	A passenger used the emergency release handle to open the door of a moving train and jumped to his death.		Trainsets were modified to prevent door levels from operating while a train is in motion.	0	1
July 2008	ICE Cologne	ICE 3	Slow	The eight-car trainset derailed as it was exiting a station. None of the 250 passengers on board were injured. All of the passengers were evacuated through doors that were still along the station platform. The incident did tie up rail access to the station and virtually halted all service for several hours.	Cracked axle.	DBAG recalled all of the ICE 3 sets from service for thorough inspections and repairs as needed.	0	0
July 2008	Trenitalia Milan	ETR-500	Slow	An out-of-service train moving at low speed separated between cars 11 and 12 due to problems with the connecting hook between them.	Equipment failure or human error.		0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
July 2008	Trenitalia Milan	ETR-500	Slow	An out-of-service train moving at low speed separated between cars 9 and 10 when the emergency brake of the rear locomotive activated.	Equipment failure or human error.		0	0
September 2008	SJ-2000 Tierp	X-2000	125 mph	Train derailment.	Axle failure.		0	0
October 2008	Thalys Gouda	PBA	<20 mph	The slow-moving train collided with a four-car electric multiple-unit as it was leaving the Gouda Station. The lead units of both trains were slightly damaged and derailed. The overhead catenary was also damaged. The Thalys service did not usually run through Gouda but was diverted to this eastern line between Amsterdam and Rotterdam due to maintenance on the primary line.	Initial reports identified a possible combination of human error (one of the operators ignoring a red signal) and technical malfunctions of the signals system.		0	0
August 2009	TGV Lille-Toulouse LC	Reseau	Unknown	The 10-car trainset struck an automobile at a grade crossing. The automobile was cut in two, and one piece was embedded under the front of the lead power car. None of the 216 passengers on board were injured.	Automobile on tracks at grade crossing.		0	1 (the auto-mobile driver)
October 2009	TGV Sud-Est	PSE	Stopped	The train's overhead electrical equipment directly connected to the pantograph caught fire. The train was unoccupied at the time and was parked on a track outside a station. The fire caused service delays into and out of the terminal, but no injuries were associated with the incident.			0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
December 2009	Eurostar Channel Tunnel	Eurostar x4	Stopped	Five trains stalled, including four inside the Channel Tunnel. More than 2,000 people were trapped in the tunnel, with some stranded for up to 16 hours.	Electronic failures caused by the buildup of ice, snow, and salt on the trains, tracks, and catenary during a record snowfall.		0	0
January 2010	Eurostar Channel Tunnel	Eurostar	Stopped	A train heading from Brussels to London became disabled in the tunnel.	On-board signal failure.		0	0
January 2010	ICE Siegburg	ICE 3	Stopped	Firefighters were called to the train station because of a heavy-smoke condition in a train coach. The 450 passengers, none of whom were injured, were safely evacuated from the train in the station and transferred onto other trains.	A small fire was caused by oil dripping onto hot brake shoes on one of the bogies.		0	0
February 2010	Eurostar-London, UK	Eurostar	Stopped	A train from Paris to London shut down near Ashford International, stranding 740 passengers for hours awaiting a “rescue train” to bring them to London.	Equipment failure.		0	0
April 2010	ICE Montabaur	ICE 1 & ICE 3	Fast	The exterior door of a trainset became dislodged and fell off the train, striking a train traveling in the opposite direction. The flying door smashed into the windows of the other train, injuring six passengers.	Door flying off one train and hitting another.		6	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
July 2010	ICE Various	ICE 1	N/A	During an intensive heat wave in Germany, many of the ICE trainsets experienced complete breakdowns of the air-conditioning units. What began as a customer service and public relations problem quickly evolved into a safety incident. On a few revenue trains carrying passengers, interior temperatures reached 122 degrees Fahrenheit. Some passengers passed out, and DBAG ultimately stopped and evacuated trains. Several passengers required medical attention, including on-scene emergency intravenous drips to treat severe dehydration.	Equipment malfunctions.	The incident exposed a weakness in the engineering of the HVAC systems.	Various	0
July 2010	TGV Sud-Est LC	Duplex	Unknown	A train collided with a truck at a grade crossing. The truck driver safely escaped. The front power car was damaged, but the train did not derail.	Truck on tracks at grade crossing.		0	0
August 2010	ICE Lambrecht	ICE 3	55 mph	A garbage truck that slid off a road and down onto the ROW was hit by a train. The truck was caught by the train and dragged along the track for several hundred yards, causing the lead power car and the first two coaches to derail. The truck also caused a significant gash, penetrating the car body, on the right side of the power car and first coach. The truck driver, the engineer, and 13 passengers were injured.	Track obstruction.		15	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
September 2010	SJ-2000 Kimstad	X-2000	80 mph	A train from Stockholm to Malmo carrying 244 passengers collided with a wheeled crane working on the ROW. There was one fatality, two passengers sustained serious injuries, and 16 others required transport to a hospital for treatment and observation.	Collision with railroad work equipment.		18	1
December 2010	ICE Fehmarn	ICE TD	Unknown	The train collided with a tractor-trailer at a grade crossing. The lead power car received damage to the nose, windshield, cab, and front bogie, but the entire trainset stayed on the rails. The 10-year-old train-set, which has a capacity of 195, was carrying only 70 passengers at the time of the incident. The truck was destroyed, and the driver was killed in the collision. The engineer received minor injuries.	Tractor-trailer on tracks at grade crossing.		1	1 (truck driver)
January 2011	ICE Zevenaar, NL	ICE 3	Slow	The train was involved in a slow-speed, sideswipe collision with a freight train. The lead power car was slightly damaged and derailed, and the front bogie of the first coach derailed when the train tried to enter the same track as the freight train, slightly damaging and derailing some empty flat cars. The remainder of the ICE train was undamaged and stayed on the rails. There were no injuries to any of the 146 passengers, who were all safely evacuated from the train and the ROW through emergency exits designed into the line-side barriers.	The cause of the incident was determined to be the theft of a 1,000-foot piece of copper wire.		0	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
February 2011	TGV Atlantique LC	Atlantique	Unknown	An intoxicated driver attempted to cross the track at a closed crossing and was struck by the train. The automobile was completely totaled and wedged under the lead power car, causing the derailment of one axle on the lead bogie and damage to the nose. The driver of the car escaped safely, and there were no injuries to the 275 passengers and crew on the train.	Intoxicated driver attempted to traverse a closed grade crossing.		0	0
February 2011	Korean Train eXpress Gyeonggi	KTX-II	55 mph	The train derailed in a tunnel as it approached the Gwangmyeong station. The trailing power car and the rear five of the train's eight cars left the rails but remained upright. One passenger was slightly injured, and the remaining 146 on board were evacuated by the crew and had to walk about a 0.5 mile out of the tunnel and to the station.	Misaligned switch caused by human error and poor maintenance.		1	0

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
July 2011	Chinese HSR Wenzhou	CHR1B and CHR2E	62 mph	Because of signal problems, train engineers were being directed by control center dispatchers to proceed with caution at speeds below 12 mph if they came across red signals. The engineer of the lead train proceeded as directed, but the ATP feature shut down his train after he passed a red signal. At that point, the compromised track-detection circuitry failed to identify the train in the block and established a green signal for the train behind it. Shortly after exiting a tunnel, the trailing train quickly came upon the lead train, which was just starting to move, and slammed into its rear end. The last car of the lead train and the next three cars derailed and were knocked off the viaduct by the collision. The lead coach/engineer's cab car and the first car of the other train also derailed but remained on the viaduct. The first car was demolished by the impact, and the second car rode up, on top of it.	Signal problems caused by a severe thunder and lightning storm. Track-detection circuitry failed to identify a train in the block and established a green signal for the train behind it.	The Railways Ministry ordered a safety review of all projects under construction, and train speeds were slowed from 215 mph to 186 mph—a regulation that remains in force. Pending projects also were suspended during the post-crash period, and the opening of the Beijing-Guangzhou line was delayed by a year.	210	40
October 2011	Eurostar Cheriton, UK	Eurostar	Unknown	A passenger opened the door while traveling at speed and fell or jumped from the train near the entry to the Channel Tunnel. Service through the tunnel was delayed for several hours.		Politicians criticized the crew's communication procedures and called for an investigation into the design and operation of the train's emergency door releases.	0	1

Date	Line	Equipment	Speed	Description of Incident	Cause	Follow-Up Actions	Injuries	Fatalities
January 2012	SJ-2000 Malmo	X-2000	Unknown	An empty trainset being moved into a station for boarding collided at speed with the concrete bumper at the end of the platform track. The engineer at the opposite end of the train sustained minor injuries. The force of the impact pushed the first car up onto the top of the powercar, and the roof and engineer's cab separated from the body of the power car. Overheard wires were also damaged.			1	0
March 2012	Amtrak Acela North Kingston, RI	Acela	Unknown	A train traveling at 100 mph from Boston to Washington, DC, derailed. The train remained upright and linear. None of the 265 passengers or crew were injured. Passengers were transferred to another train, and a crane was required to lift the trainset back on the track.	Under investigation.		0	0

APPENDIX B:
A CATALOG OF BEST SECURITY PRACTICES

While transportation security clearly has improved since 9/11, the basic inventory of security measures and best practices has changed little since 2001, although there have been improvements and refinements in security measures.

Best Practices: The Latest Developments

- Threat analysis is better informed by computerized databases that provide details and statistical analysis of past terrorist incidents.
- Random passenger-screening regimes have been introduced in some large urban rail systems (e.g., New York, Boston, Los Angeles, AMTRAK).
- Improved CCTV is in place, utilizing more-sophisticated software that can, for example, alert authorities to suspicious movement or stationary items.
- Vapor-wake-detection canines are being used that are effective for dealing with moving groups of people rather than single individuals or objects.
- Explosives detection is constantly being improved, with slow progress toward remote, or “standoff,” detection.
- Behavioral detection techniques have been implemented and are being improved, although they remain controversial.
- Suspicious-activity reports are being systematized.
- The public is being enlisted in surveillance efforts.
- Security is now a criterion in train and coach design and construction.

Best Practices: Intelligence and Threat Analysis

- Periodic meetings with federal, state, and local authorities covering stations and ROWs.
- Analysis of local crime patterns.
- Enlistment of vendors in stations, along with merchants, parking attendants, and other surrounding stations, in awareness programs.
- Enlistment of passengers in “see something, say something” programs facilitated through mobile phones.

Best Practices: Stations

- Designed to have open rather than confined spaces, no narrow corridors.
- Designed to accommodate temporary increases in security.
- Good visibility for surveillance, including CCTV cameras.
- Good lighting, no dimly lit corners.
- Target hardening to withstand blasts and prevent catastrophic damage from external, large vehicle-borne bombs.
- No highly combustible materials or sources of toxic fumes or shrapnel.
- No hiding or hidden spaces.
- Reversible fans for the evacuation of contaminated air or smoke.
- Transparent elevators and, where possible, walls.
- Effective CCTV coverage with good resolution, linked with analytic software.
- Bomb-resistant, well-placed trash containers utilizing transparent trash bags, frequently emptied.
- Removal of storage lockers or their separation to safer portions of the station.
- Designed to be easy to maintain and well maintained.
- Adequate emergency exits.
- Designated evacuation routes.
- Facilitated emergency response.
- Safe sites within the station for cases where evacuation is unfeasible.
- Visible staff and security presence.
- Explosives-detection canine patrols.
- Chemical- and radioactive-substances detection systems.
- Staff trained in emergency procedures (dealing with suspicious objects, active shooters, etc.).

- Station staff and rail personnel visibly badged.
- Vendors vetted.

Best Practices: Track Protection

- Infrastructure and ROW design to minimize the potential for catastrophic consequences such as cars plunging off viaducts or HSR incidents compromising other structures. (Extra guardrails enabled the Nevsky Express in 2007 to transit a bridge before derailing despite the bombing of the rails, instead of the cars falling off the bridge.)
- Seamless rails.
- Solid roadbeds.
- Tamper-detection systems on rails.
- ROWs fenced, alarmed, and patrolled.
- Signaling systems protected against cyber intrusions.
- ROW search protocols in place.
- CCTV coverage of critical sections (bridges, tunnels, etc.).
- Sweep trains that precede daily traffic.
- Rail staff and employees trained to recognize suspicious activity and objects.

Best Practices: Passenger Security

- ID checks.
- Passenger-screening protocols in place, vetted and tested for constitutionality, legality, public tolerance (in place in AMTRAK and some commuter rail systems in the United States).
- Explosives-detection regimes for selected passengers (explored in U.S. pilot projects).
- Metal detectors and luggage x-ray (currently used only for Eurostar).
- Explosives-detection canines on platforms and trains.
- CCTV on coaches to discourage ordinary crime and provide investigative leads if an incident occurs.

- Random armed security (visible and undercover) presence in stations and on trains.
- Riders enlisted in “see something, say something” campaigns.

BIBLIOGRAPHY

A large number of sources and interviews were utilized in the research for this report, including those listed in the following bibliography.

"2 Killed, Nearly 100 Injured in Spanish Train Accident." *EFE World News Service*. March 30, 2002.

"49 CFR Parts 223, 229, 232, and 238 Passenger Equipment Safety Standards; Proposed Rule." Federal Railroad Administration, U.S. Department of Transportation. June 17 1996.

"California High-Speed Rail Project International Case Studies." California High-Speed Rail Authority. October 2011.

"China: Dozens Die As Bullet Trains Collide in Zhejiang." *BBC News*. July 24, 2011.

"Derailed." *System Failure Case Studies*. Vol. 1, Issue 5. National Aeronautics and Space Administration. March 2007.

"Design Flaws and Poor Management Caused Wenzhou Collision, Report Confirms." *Railway Gazette International*. January 9, 2012.

"Facts and Figures 2009: DB Mobility Logistics." Deutsche Bahn AG, Berlin, Germany.

"Gouda Rail Collision Investigation." www.safetynews.co.uk. October 2008.

"High-Speed Intercity Passenger Rail ("HSIPR") Program; Notice." Federal Railroad Administration, U.S. Department of Transportation. June 23, 2009.

"High-Speed Passenger Rail Safety Strategy: Version 1.0." Office of Railroad Safety, Federal Railroad Administration, U.S. Department of Transportation. November 2009.

"Japanese Rail Company Search for Crash Clues." *The Guardian*. April 26, 2005.

"Long-Distance Travel in China: Unprecedented Comfort, Clean Speed and Robust Reliability." Bombardier Transportation, Hennigsdorf, Germany. 2010.

"Railway Safety Performance in the European Union." European Railway Agency. Valenciennes, France. 2012.

"Redefining Very High Speed: Economy and Ecology in Harmony." Bombardier Transportation, Hennigsdorf, Germany. 2010.

"Technical Criteria and Procedures for Evaluating the Crashworthiness and Occupant Protection Performance of Alternatively-Designed Passenger Rail Equipment for Use in Tier I Service: Draft Report." Federal Railroad Administration, U.S. Department of Transportation. September 16, 2010.

"TGV (Thalys type) Collision with an Intercity Train Crash in Netherlands, Gouda." *Reuters*. October 13, 2008.

"Train Derailment Causing Major Problems for Metro North and Amtrak." WABC-New York. October 29, 2004.

"Vision for High-Speed Rail in America." Federal Railroad Administration, U.S. Department of Transportation. April 2009.

Accident/Incident Investigation Assignments. Federal Railroad Administration, Office of Safety, Headquarters, January–November 2004.

Amos, Paul, Dick Bullock, and Jitendra Sondhi. *High-Speed Rail: The Fast Track to Economic Development?* The World Bank, Beijing, China. July 2010.

Anbari, Frank T., Paul Giammalvo, Paul Jaffe, Craig Letavec, and Rizwan Merchant. "The Chunnel Project." The Project Management Institute, George Washington University. Washington, DC. 2005.

Andersson, Evert, Anneli Orvnas, and Rickard Persson. *Radial Self-Steering Bogies: Development, Advantages and Limitations*. Railway Group, Centre for Research and Education in Railway Engineering, KTH (Royal Institute of Technology), Stockholm. 2007.

Andreev, Vladimir E., Sergey M. Zakharov, and Viktor O. Pevsner. *Present State and Standardization Plans for High-Speed Rail Systems in Russia*. RZD (Russian Railways). October 2010.

Beer, Armin. *Test-Strategy Patterns: Testing Safety-Critical Even-Based Systems*. Siemens IT Solutions and Services PSE. 2007.

Bing, Alan J. *Collision Avoidance and Accident Survivability*, Vol. 1: *Collision Threat.* Research and Special Programs Administration, U.S. Department of Transportation. March 1993.

Brabie, Dan, and Evert Andersson. "An Overview of Some High-Speed Train Derailments: Means of Minimizing Consequences Based on Empirical Observations." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. (222): 441–463, 2008.

Brabie, Dan. *On the Influence of Rail Vehicle Parameters on the Derailment Process and Its Consequences*. KTH Engineering Sciences, Royal Institute of Technology. Stockholm. 2005.

Carolan, Michael, and Laura Sullivan. “Potential Scenarios of Concern for High-Speed Rail Operations.” *Proceedings of the 2011 Joint Rail Conference,* Pueblo, CO, March 16–18, 2011.

Carroll, Anya A., Neil R. Meltzer, and John E. Carpenter. *Intruder and Obstacle Detection Systems (IODS) for Railroads: 1998 Requirements Workshop. Final Report, December 2001*. Research and Special Programs Administration, U.S. Department of Transportation. 2001.

Casares, Pedro, and Pablo Coto-Millan. “Passenger Transport Planning. A Benefit-Cost Analysis of the High-Speed Railway: The Case of Spain.” *Atlantic Review of Economics*. Vol. 2. 2011.

Colliard, Jacques. “Action Driven by the UIC—The International Union of Railways—in the Security Field.” *European Railway Review*. August 2004.

Colliard, Jacques. “Development and Perennial Nature of Railway Security Policies.” *European Railway Review*. July 2005.

Colliard, Jacques. “Insuring Sustainable Development of Security.” *The International Railway Journal*. January 2005.

Comeau, Ed, and Alisa Wolf. “Fire in the Chunnel!” *NFPA Journal*. March-April 1997.

Davies, Richard. Network Rail Emergency Planning and Response. Briefing. Network Rail, 2011.

de Rus, Gines, and Gustavo Nombela. *Is Investment in High-Speed Rail Socially Profitable?* Department of Applied Economic Analysis, University of Los Palmas, Los Palmas, Spain. 2005.

Design of New Lines for Speeds of 300-350 KM/H State of the Art: First Report. High Speed Department, International Union of Railways. October 25, 2001.

Esveld, Coenraad, and Valeri Markine. *Slab Track Design for High-Speed*. Delft University of Technology, Delft, Netherlands. 2001.

Evans, A. W. “A Statistical Analysis of Fatal Collisions and Derailments of Passenger Trains on British Railways: 1967 – 1996.” *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. Vol. 211:73–86, 1997.

France TGV Mediterranean. Université Paris-Est, LATTS Laboratoire Techniques Territoires Sociétés. 2009.

Goodman, Al. “6 Killed as Train Derails in Spain.” *CNN*. August 21, 2006.

Goossens, Hugo. *Maintenance of High-Speed Lines*. International Union of Railways, Paris. September 2010.

Highway-Rail Grade Crossing Guidelines for High-Speed Passenger Rail. Office of Railroad Safety, Federal Railroad Administration, U.S. Department of Transportation. November 2009.

Jackson, Chris. "Pioneer High-Speed Line Is Still at the Cutting Edge." *Railway Gazette International*. (160): 10, October 2004.

Janic, M. "High-Speed Rail and Air Passenger Transport: A Comparison of the Operational Environmental Performance." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.* Vol. 217: 259–269, 2003.

Jehanno, Aurelie, Derek Palmer, and Ceri James. *High-Speed Rail and Sustainability*. The International Union of Railways, Paris. November 2011.

Johnson, Ian. "At Least 35 Killed and 210 Hurt in Crash of 2 Trains in China." *The New York Times*. July 23, 2011.

Johnson, Ian. "Train Wreck in China Heightens Unease on Safety Standards." *The New York Times*. July 24, 2011.

Jonston, Bob. "Acela Report." *Trains Magazine*. 52–57, December 2001.

Kirkland, C. J. "The Fire in the Channel Tunnel." Halcrow Consulting Engineers. 2002.

Kirkpatrick, S. W., M. Schroeder, and J. W. Simons. "Evaluation of Passenger Rail Vehicle Crashworthiness." *The International Journal of Crashworthiness*. (6) 1: 95–106, 2001.

Kunishima, Masahiko, and Yukihiro Ishihara. "Concrete Flaking in a Shinkansen Tunnel of West Japan Railway Co." Failure Knowledge Database/100 Selected Cases.

LaFraniere, Sharon. "Design Flaws Cited in Deadly Train Crash in China." *The New York Times*. December 28, 2011.

Lauby, Robert C. "Development of U.S. High-Speed Rail Safety Requirements." Federal Railroad Administration, U.S. Department of Transportation. 2011.

Leboeuf, Michel. *The Infrastructure Access Charges Issue in France*. SNCF. March 2008.

Leveque, Didier, Yannick Chauveau, and Louis Dangas. *Numerical Assessment on Structure During an Explosion*. Centre D'Ingenierie Du Materiel. October 2007.

Lewis, J. H. “Structural Crashworthiness—Possibilities and Practicalities.” *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. Vol. 216: 117–121, 2002.

Lindahl, Martin. *Track Geometry for High-Speed Railways: A Literature Survey and Simulation of Dynamic Vehicle Response*. Department of Vehicle Engineering, Royal Institute of Technology (KTH), Stockholm. 2001.

Lonner, Henrik, and Klas Nordqvist. *Evaluation and Improvement Proposals of Uninterruptable Power Supply of the Electronic System, Within the Battery System, for X2000 Trains at EuroMaint AB*. Department of Energy and Environment, Chalmers University of Technology, Goteborg, Sweden. 2009.

Lopez Pita, Ing A. *Operating High-Speed Lines Carrying Mixed Traffic: Experience Gained and Current Trends*. International Union of Railways. October 2001.

Masson, Elisa, and Lars Hoefener. *Aerodynamics in the Open Air (AOA) European Project, WP2 Crosswind Issues—Summary Report*. Rail Safety and Standards Bureau (UK). October 2008.

McDonald, Joe. “China’s Enthusiasm for High-Speed Rail Stalls After Fatal Crash.” *The Associated Press*. August 14, 2011.

Nishiyama, Takao. “High-Speed Rail System in Japan.” East Japan Railway Company. 2010.

Noguchi, Tatsuo, and Toshishige Fujii. “Minimizing the Effect of Natural Disasters.” *Japan Railway & Transport Review*. (23), March 2000.

Okada, Hiroshi. “High-Speed Railways in China.” *Japan Railway & Transport Review*. (48), August 2007.

Orlova, Anna, and Uri Boronenko. “The Anatomy of Railway Vehicle Running Gear.” *Handbook of Railway Vehicle Dynamics*. Boca Raton, FL: CRC Press, Taylor & Francis Group. 2006. pp. 39–83.

Pajunen, Kirsi, Anders Lundstrom, and Bart Accou. *The Future Role of European Railway Agency: Report on the Work of Reflection Groups of National Safety Authorities and National Investigation Bodies*. European Railway Agency. Valenciennes, France. November 2010.

Perez-Martinez, P. J., and E. Lopez-Suarez. *Performance of the High-Speed Rail in Spain in the Context of the New Regulation Framework. Evidence from the Madrid-Seville HSR Corridor*. Polytechnic University of Madrid, Transport Research Center. 2005.

Persson, Rickard. *Tilting Trains: Technology, Benefits and Motion Sickness*. KTH (Royal Institute of Technology), Stockholm. May 2008.

Peterman, David, John Frittelli, and William J. Mallett. *High-Speed Rail (HSR) in the United States*. Congressional Research Service, Washington, DC, December 8, 2009.

Progress Report on the Implementation of the Railway Safety Directive (Directive 2004/49/EC) End of the Railway Interoperability Directives (Directives 96/48/EC and 2001/16/EC). Commission of the European Communities, Brussels. 2009.

Raghunathan, Raghu S., H. D. Kim and T. Setoguchi. "Aerodynamics of High-Speed Railway Train." *Progress in Aerospace Sciences*. 38: 469–514, 2002.

Rail Accident Report: Overhead Line Failure, St. Pancras International 23 September 2009. Rail Accident Investigation Branch, Department for Transport (UK), December 2010.

Railway Investigation Report R08M0015 Main-Track Derailment VIA Rail Canada Inc. Train Number 15 Mile 23.32, Mont-Joli Subdivision, Near Matapedia, Quebec, March 12, 2008. Transportation Safety Board of Canada. 2008.

Railway Safety Performance in the European Union. European Railway Agency. Valenciennes, France. 2010.

Railway Safety Performance in the European Union. European Railway Agency. Valenciennes, France. July 2011.

Report on Niigata Chuetsu Earthquake. East Japan Railway Company. 2005.

RSSB T118 Whole Train Dynamic Behaviour in Collisions and Improving Crashworthiness—Phase 1 Report. The Rail Safety & Standards Board (UK). 2006.

Santos-Reyes, J., A. N. Beard, and R. A. Smith. "A Systematic Analysis of Railway Accidents." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. Vol. 219: 47–65, 2005.

Siebert, Loren. "Using GIS to Map Rail Network History." *Journal of Transport History*. (25) 1: 84–104, 2004.

Simpson, Peter. "China Bullet Train Crash Caused By 'Design Flaws' and 'Sloppy Safety'." *The Telegraph*. December 28, 2011.

Smith, Roderick A. "The Japanese Shinkansen: Catalyst for the Renaissance of Rail." *The Journal of Transport History.* 24 (2): 222–237, 2003.

Soejima, Hiroumi. “Railway Technology in Japan—Challenges and Strategies.” *Japan Railway & Transport Review*. 36: 4–13, September 2003.

Strategic European Rail Research Project—Safe Interiors. Rail Safety and Standards Bureau (UK). December 2010.

Sutton, A. “The Development of Rail Vehicle Crashworthiness.” *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. Vol. 216: 97–108, 2002.

Takagi, Kotofusa. *New Challenges to Shinkansen: Fight Against Big Earthquake*. East Japan Railway Company. 2008.

Takashima, Shuichi. “Railway Operators in Japan: Hokkaido.” *Japan Railway & Transport Review*. (28), September 2001.

Takemoto, Kiyohiro. *Japanese Standards for High-Speed Rail Systems*. East Japan Railway Company. October 2010.

Tanaka, Hiromasa. *High-Speed Rail and Its Contribution to Society: Japan’s Experience*. Central Japan Railway Company (JRC). June 2010.

Technical Standard System of China Railway on High-Speed. China Academy of Railway Sciences. October 2010.

Track Safety Standards Compliance Manual. Office of Safety Assurance and Compliance, Federal Railroad Administration, U.S. Department of Transportation. January 2002.

Understanding and Views on High-Speed Railway Standardization Activity. China Academy of Railway Sciences. October, 2010.

Valonen, Kai. *Investigation of Rail Accidents—International Comparison: Summary in English*. Helsinki University of Technology. March 6, 2000.

Wang, Yanhui, Xuemei Xia, and Hao Cui. “The Research on Emergence Mechanism of High-Speed Rail Way Accident.” *Advanced Materials Research*. (186): 116–120, 2011.

Whitford, Robert K., Matthew Karlaftis, and Konstantinos Kepaptsoglou. “High-Speed Ground Transportation: Planning and Design Issues.” *The Civil Engineering Handbook*, 2nd Ed. Chap. 60. Boca Raton, FL: CRC Press, LLC. 2003.

Wood-Heath, Moya, and Martin Annis. *Working Together to Support Individuals in an Emergency or Disaster, Project Final Report*. British Red Cross. May 2004.

Yanase, Naoto. “Necessities for Future High-Speed Rolling Stock.” International Union of Railways. January 2010.

Zimmermann, Karl. 1996. “Eurostar Runs Fast and Deep.” *Trains Magazine*. 60–65, April.

ABBREVIATIONS AND ACRONYMS

AVE	Alta Velocidad Espanola (Spain)
CCTV	Closed Circuit Television
CTCS	Chinese Train Control System
DB	Deutsche Bundesbahn (Germany)
EMU	Electrical Multiple Unit
EU	European Union
FPA	Fatalities Per Attack
FPD	Fatalities Per Device
HSR	High-Speed Rail
ICE	Intercity Express (Germany)
IED	Improvised Explosive Device
IPA	Injuries Per Attack
IPD	Injuries Per Device
IRA	Irish Republican Army
JNR	Japanese National Railways
JR Group	Japan Railways Group
KTX	Korean Train Express (South Korea)
MTI	Mineta Transportation Institute
MOR	Ministry of Railways (China)
NTV	Nuovo Trasporto Viaggiatori (Italy)
PTC	Positive Train Control
RENFE	Red Nacional de los Ferrocarriles Espanoles (Spain)
ROW	Right-of-Way
SJ	Statens Jarnvajar (Sweden)
SNCF	Societe Nationale des Chemins de fer Francais
TGV	High-Speed Train in France (train a grande Vitesse)
Trenitalia	Italian Railways
TSA	Transportation Security Administration
UIC	International Union of Railways - I'Union Internationale des Chemins de fer
UITP	International Association of Public Transport - Union International de Transports Publics
UK	United Kingdom

ABOUT THE AUTHORS

BRIAN MICHAEL JENKINS

Brian Michael Jenkins is the director of the Mineta Transportation Institute's National Transportation Center and since 1997 has directed the Institute's continuing research on protecting surface transportation against terrorism and other serious forms of crime.

He received a Bachelor of Arts degree in fine arts and a Masters degree in history, both from UCLA. He also studied at the University of Guanajuato, Mexico, and in the Department of Humanities at the University of San Carlos, Guatemala, where he was a Fulbright Fellow and received a second fellowship from the Organization of American States.

Commissioned in the infantry at the age of 19, Mr. Jenkins became a paratrooper and ultimately a captain in the Green Berets. He is a decorated combat veteran, having served in the Seventh Special Forces Group in the Dominican Republic during the American intervention and later as a member of the Fifth Special Forces Group in Vietnam (1966–1967). He returned to Vietnam on a special assignment in 1968 to serve as a member of the Long Range Planning Task Group; he remained with the Group until the end of 1969, receiving the Department of the Army's highest award for his service. Mr. Jenkins returned to Vietnam on an additional special assignment in 1971.

In 1983, Mr. Jenkins served as an advisor to the Long Commission, convened to examine the circumstances and response to the bombing of the U.S. Marine Barracks in Lebanon. In 1984, he assisted the Inman Panel in examining the security of American diplomatic facilities abroad. In 1985–1986, he served as a member of the Committee of the Embassy of the Future, which established new guidelines for the construction of U.S. diplomatic posts. In 1989, Mr. Jenkins served as an advisor to the national commission established to review terrorist threats following the bombing of Pan Am 103. In 1993, he served as a member of the team contracted by the Port Authority of New York & New Jersey to review threats and develop new security measures for the World Trade Center following the bombing in February of that year.

In 1996, President Clinton appointed Mr. Jenkins to the White House Commission on Aviation Safety and Security. From 1999 to 2000, he served as an advisor to the National Commission on Terrorism, and since 2000, he has been a member of the U.S. Comptroller General's Advisory Board.

Mr. Jenkins serves as a Senior Advisor to the President of the RAND Corporation. He is a Special Advisor to the International Chamber of Commerce (ICC) and a member of the advisory board of the ICC's investigative arm, the Commercial Crime Services. Over the years, he has served as a consultant to or carried out assignments for a number of government agencies, including the Department of Homeland Security (DHS). As part of its international project to create a global strategy to combat terrorism, the Club of Madrid in 2004 appointed Mr. Jenkins to lead an international working group on the role of intelligence.

Mr. Jenkins is the author of numerous published research reports, books, and articles on terrorism and security. His latest book is *When Armies Divide.*

CHRISTOPHER KOZUB

Christopher Kozub has assisted the Mineta Transportation Institute on various research projects since 2010. From 2000 to 2010, Mr. Kozub was an associate director of the Edward J. Bloustein School of Planning and Public Policy at Rutgers University, working with the National Transit Institute (NTI), the Voorhees Transportation Center, and the Center for Transportation Safety, Security, and Risk. At Rutgers, he was the principal investigator on several surface-transportation research, training, and outreach projects funded by the U.S. Department of Transportation (DOT) and the Department of Homeland Security (DHS). These projects investigated system safety, emergency management, system security, and terrorism awareness and response.

Mr. Kozub's background includes more than 30 years in emergency services, transportation safety and security, and training. For more than 15 years, he has worked with federal agencies, surface-transportation trade associations, and labor organizations to develop and implement safety and security training programs for frontline employees, supervisors, and emergency responders in transportation incident information and data analysis and to broaden their ability to develop training and educational programs and materials, including courses, seminars, workshops, case studies, and exercise scenarios. He has also testified before Congress on public transit operational and infrastructure security.

Prior to joining Rutgers, he was director of training for the Operation Respond Institute (ORI), where he worked with Amtrak to develop and deliver security, safety, and tactical emergency-response training to more than 16,000 responders in connection with the Acela high-speed rail service.

Mr. Kozub has held senior management positions at emergency-services training centers, working with the Association of American Railroads to provide specialized hazardous-materials training. He worked with the Port Authority of New York & New Jersey to develop and deliver fire, rescue, and hazardous-materials training for their police and emergency services departments, as well as a specialized Weapons of Mass Destruction program following the 1995 Tokyo subway attacks.

BRUCE ROBERT BUTTERWORTH

Bruce Butterworth has had a distinguished government career, working at congressional, senior policy, and operational levels. Between 1975 and 1980, as a professional staff member for the House Government Operations Committee, he ran investigations and hearings on many transportation-safety issues, particularly in aviation. He spent 11 years in the Department of Transportation, eight of them in the Office of the Secretary. He managed negotiations on air and maritime services in the General Agreement on Tariffs and Trade (GATT) (now the World Trade Organization [WTO]), chaired U.S. delegations to United Nations committees, dealt with transport and aviation issues related to border inspections, and was part of the response to the bombing of Pan Am 103.

Mr. Butterworth held two executive posts in aviation security and in both worked closely with Congress as the informal but primary liaison. He was Director of Policy and Planning (1991–1995), establishing strategic, long-term, and contingency plans and federal rules. As Director of Operations (1995–2000), he was responsible for federal air marshals, hijacking response, and 900 field agents; he worked to improve security and the performance of security measures at U.S. airports and by U.S. airlines worldwide. He ran the FAA's aviation command center, successfully managing the resolution of hijackings and security emergencies. He launched a successful program of dangerous-goods regulation and cargo security after the 1995 ValuJet crash, oversaw the conversion of the air-marshal program to a full-time program with high standards, was a key player in the response to the ValuJet and TWA 800 accidents, and was a frequent media spokesperson. He worked closely with Congress, the National Security Council staff, the intelligence community, law enforcement agencies, and authorities of other nations.

From 2000 to 2003, he was an associate director at the U.S. Holocaust Memorial Museum, responsible for security and building operations. He designed and implemented a "best practice" procedure to deal with mail that could contain anthrax, and he developed and conducted new, comprehensive emergency planning procedures and exercises. Between January 2003 and September 2007, he was one of two deputy directors in a 1,300-person engineering directorate at NASA's Goddard Space Flight Center, managing workforce planning, budgeting, and human-capital management for complex robotics space missions, substantially reducing overhead and improving workplace safety there. He also worked with the Department of Homeland Security (DHS) on information sharing.

Mr. Butterworth is a research associate at the Mineta Transportation Institute. In this capacity, he has co-authored several reports with Brian Michael Jenkins, including one for the State of California on security risks created by highway-borne hazardous materials. In February 2009, he published with Mr. Jenkins an opinion piece on information sharing, and on March 23, 2010, he published an article in the Washington Post on intelligence and aviation security.

In 2011, his leading role in creating MTI's unique database of attacks on public surface transportation and in creating and delivering nearly all the briefings to the Transportation Safety Administration's (TSA's) front-line bomb-appraisal officers was recognized in a DHS High Impact award.

Mr. Butterworth received a Master of Science degree from the London School of Economics in 1974 and a Bachelor of Arts degree from the University of the Pacific in 1972 (magna cum laude). He was a California State Scholar and a Rotary Foundation Fellow. He has received numerous special achievement and performance awards.

RENEE HAIDER

Renee Haider is a research associate at the Mineta Transportation Institute. She has more than twenty years of experience conducting research on safety and security in the surface-transportation sector and applying the research results to practice. She has served as a project manager or key team member on an array of research and training projects for the

Department of Homeland Security (DHS), the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA), the Federal Highway Administration (FHWA), the Transit Cooperative Research Program (TCRP), and the National Cooperative Highway Research Program (NCHRP). Ms. Haider has also worked with several University Transportation Centers (UTCs) and has consulted with public transportation organizations across the United States and Canada. Prior to joining MTI, she served as an associate director of the National Transit Institute (NTI) at Rutgers University. Ms. Haider holds a Masters Degree in political science from Rutgers University.

JEAN-FRANCOIS CLAIR

Jean-Francois Clair is a former Inspector General of Police. He served 35 years in France's Security Service, the Directorate of Territorial Security (Direction de la Surveillance du Territoire) (DST), the country's internal intelligence system with responsibilities similar to those of the FBI in the United States and MI-5 in the United Kingdom. From 1983 to 1997, he was the head of DST's Anti-Terrorist Branch. In 1998, he was promoted to deputy director of DST, a position he held until his retirement in 2007.

Dr. Clair received a PhD in Public Law from the University of Paris in 1969 and graduated from the Institute for Higher Studies for National Defense (Institut des haute études de défense nationale) (IHEDN) in 1993.

Dr. Clair currently teaches in the Graduate School of International Affairs at the institut d'Etudes Politiques de Paris (Sciences-Po) and at the Institute for International and Strategic Research (IRIS). He is a frequent lecturer at the George Marshall Center in Garmisch, Germany, and he has participated in international symposia on terrorism and security issues (Singapore, 2007 and 2008; Berlin, 2008; and Oslo, 2009). He is also in charge of research for the French Administration.

PEER REVIEW

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