Grade Crossing Safety and Economic Issues in Planning for High-Speed Rail Systems

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A serious problem facing planners of high-speed rail (HSR) systems in the United States is the difficulty of locating suitable rights-of-way in heavily built-up metropolitan areas. A proposed solution is often the use of existing rail corridors that generally have at-grade crossings in the close-in environs of a city. Highway grade crossings are incompatible with HSR operation because of the public safety hazards presented by the speed and frequency of train service in HSR corridors. Nevertheless, the cost and, in some cases, the feasibility of grade separating these existing routes essentially preclude their use if all highway grade crossings must be eliminated. Safety and economic issues that should be considered by planners and designers in determining whether at-grade crossings are appropriate for the system they are planning are discussed. It is concluded that, although no one can expect a high-speed passenger rail system to have a perfect safety record indefinitely, the public will demand that HSR safety be equivalent to or better than that of existing conventional rail passenger service and comparable with that of air travel. Therefore, ways must be found to improve safety at crossings. In the final analysis, the cost of making grade crossings sufficiently safe for use on HSR lines may approach the cost of eliminating them altogether. The cost savings versus the liabilities of not fully eliminating grade crossings must be evaluated on a case-by-case basis.

Intercity passenger rail service in the United States has reemerged as an effective competitor and a complement to the automobile and air modes in corridors that are 200 to 400 mi long. Air travel congestion has resulted in delays, cancellations, and poor adherence to schedules. Intercity automobile travel has deteriorated with urban congestion and inadequate or incomplete roadway networks that are increasingly in need of repair. High-speed rail (HSR), as introduced first in Japan and further developed more recently in Europe, is capable of providing competitive travel time and cost in targeted urban markets. A number of U.S. applications are in the feasibility and conceptual planning phases.

A serious problem facing planners of HSR systems in the United States is the difficulty of locating suitable rights-of-way in heavily built-up metropolitan areas. A proposed solution is often to use existing rail corridors in the close-in environs of a city [similar in concept to the TGV's (Très Grande Vitesse) use of conventional trackage close to Paris and Lyons] that provide access but have some penalties (e.g., speed restrictions due to curves and rail and highway grade crossings). Highway grade crossings are generally incompatible with HSR operation because of the public safety hazards presented by the speed and frequency of train service in HSR corridors. Nevertheless, the cost and, in some cases, the feasibility of grade separating existing routes essentially preclude their use if all highway grade crossings must be eliminated.

Safety and economic issues that should be considered by planners and designers in determining whether at-grade crossings are appropriate for the system they are planning are investigated.

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BACKGROUND

Foreign Experience

The development of high-speed passenger rail technologies has taken place almost entirely in Japan, France, Great Britain, and Germany. These countries have consistently placed a high priority on passenger rail service as a matter of national policy and have developed extensive passenger networks. The Japanese introduced the first high-speed line in 1964 between Tokyo and Osaka. The Shinkansen or "bullet" train system, which has been expanded to 1,225 route miles, has entirely new track and equipment and no grade crossings. The French TGV Southeast Line, which opened in 1981 between Paris and Lyons, operates at up to 168 mph on new concrete tie track with no at-grade crossings. In the environs of Paris and Lyons, as well as on other conventional rail lines in France, TGV trains operate at slower speeds, still providing a high level of service and ride comfort. The conventional lines have at-grade highway crossings in suburban and rural areas.

The basic technology options for high-speed service including combinations of equipment, track, and propulsion types are summarized next.

Technology Options

- Improved conventional (IC) equipment on upgraded existing tracks: This option is the least costly and uses diesel powered "tilt body" or conventional equipment with maximum speeds of about 125 mph. This option involves sharing track with freight and commuter traffic. Many highway crossings are at grade.

- Advanced technology (AT) on existing track: Different versions of electric "tilt body" and more conventional trains, which can attain speeds of up to 150 mph on existing tracks, are being developed and considered by a number of countries.
- HSR: New equipment is used on partly or totally new track. State-of-the-art equipment on new dedicated track, capable of supporting speeds of up to about 188 mph, on which at-grade crossings are completely eliminated or operate under the most stringent control.
- Very high-speed rail (VHSR) (250 to 300 mph) goes beyond steel wheels on rail (e.g., maglev) and is totally grade separated.

Table 1 is a list of existing foreign HSR operations.

Future Foreign Activity

The Germans and the French are currently planning and constructing extensive application of HSR technologies. The Japanese have already established a high-speed network.

The countries of western Europe are discussing and planning a network of high-speed rail to serve an integrated travel market. The European Conference of Ministers of Transport (ECMT) is an intergovernmental organization that includes 19 European countries and 4 associated countries (Australia, Canada, Japan, and the United States). The ECMT studies transportation policy and the organization of railways and rail transportation. This organization has adopted a formal common definition of high-speed railway lines for main international travel and established 156 mph as the nominal speed for new lines of international importance (*1*). (In the United States, 125 mph is normally accepted as the boundary line between conventional rail and HSR.) The high-speed lines in service, under construction, and being planned as part of that network are given in Table 2.

The estimated cost of the new European lines varies from about $5.2 million to $32 million per mile, depending on the terrain, urban development along the route, and the number of highway crossings to be grade separated. The extent to which highway grade crossings must be eliminated can influence the economic feasibility of new lines.

United States

In the United States a number of private and state-sponsored initiatives to introduce high-speed rail are in progress. HSR or VHSR systems are being, or have been, studied for the intercity corridors listed in Table 3.

The magnitude of a project for implementing an HSR system and the complexity of its interrelated issues necessitate careful and comprehensive planning. Economic viability is an extremely important consideration. Selection of a technology and identification of a feasible and operationally adequate corridor are only two of the factors to be evaluated for candidate corridors that have high populations and densities, intercity travel affinity, and a physical separation attractive for HSR competition with other modes. The decision of whether to grade separate all highway crossings is an important consideration in many of the corridors listed in Table 3.

RAIL-HIGHWAY GRADE CROSSING DILEMMA

In addition to defining a suitable corridor that provides the physical environment for high-speed operation as well as

TABLE 1 EXISTING FOREIGN HSR OPERATIONS

Country	Train Designation	Technology Option	Maximum Speed (mph)	Least Restrictive Crossing
Germany	IC	AT	125	At grade
France	TGV	HSR	168	Grade separated
Japan	Shinkansen	HSR	153	Grade separated
Great Britain	HST	IC	125	At grade
Italy	Pendalino	AT	125	At grade
Spain	Talgo	AT	125	At grade
Sweden	X-2	AT	125	At grade
Canada	LRC	IC	125	At grade

TABLE 2 EUROPEAN HIGH-SPEED LINES OVER 156 mph

Country	Line	Distance (mi)	Status	Maximum Speed (mph)
France	Paris-Lyons	267	Operating	169
Italy	Rome-Florence	163	Under construction	156
Germany	Mannheim-Stuttgart	65	Under construction	156
Germany	Hanover-Würzburg	204	Under construction	156
France	Paris-Le Mans-Tours	200	Under construction	188
France–United Kingdom	Paris-London Channel	100	Being planned	188
Belgium-Netherlands	Brussels-Amsterdam	100	Being planned	188
Germany	Cologne-Frankfurt	100	Being planned	185
Germany	Nuremburg-Ingoldstaadt	63	Being planned	185
Germany	Raitart-Offenburg	31	Being planned	185
France	Paris-Strasbourg	668	Being planned	188
Italy	Milan-Bologna	125	Being planned	156

TABLE 3 U.S. CANDIDATE HSR CORRIDORS

Corridor	Length (mi)	Technology	Maximum Speed (mph)	Estimated Cost ($ billions)
Los Angeles–Las Vegas	230	VHSR	250	1.9
Tampa-Orlando-Miami	295	HSR	120–180	1–5
Montreal–New York	365	HSR	185	1.5
Washington–Boston–Northeast Corridor	455	IC/AT	125	2.2
Philadelphia-Pittsburgh	320	HSR/VHSR	160–250	7–10
Chicago-Milwaukee	79	VHSR	250	1.2
Chicago-Detroit	279	IC	125	0.7
Houston–Dallas–Fort Worth	273	HSR	185	1.7
Cleveland-Columbus-Cincinnati	244	HSR	170	3.0

time-effective access to the cities served with acceptable social and environmental impacts, HSR planners must decide how to handle the many intersections where roadways and existing railways cross the HSR corridor. The safest solution is to eliminate such intersections by grade separation, road relocation, or closure. Grade crossings of railroads and highways represent the highest fatal accident category for rail in the United States. Rail grade crossings may represent a significant public concern about HSR implementation and certainly represent a significant planning element. In a recent study of an HSR application in the Houston–Dallas–Fort Worth corridor, for example, the cost of grade separations for highways, which included 135 structures four of which had a total length of approximately 13 mi in dense urban areas, represented 17 percent of the total cost of the project, or $290 million (2). This illustrates the magnitude of the problem of providing complete grade separation in a typical HSR corridor.

Where grade separation is not feasible or is prohibitively expensive, at-grade intersections between HSR and highway may be necessary. French and British trains routinely cross highways at up to 125 mph; gates, warning sounds, and on-train closed-circuit television are used. The location of the grade crossing and the type of service dictate appropriate protection.

There has been considerable experience with at-grade railroad-highway crossings in the United States; more than 190,000 public crossings are currently in service. Accident data indicate that accidents can be reduced by 60 percent by installing flashing lights and by 90 to 95 percent by installing arms and flashing lights on passive controls. Railroad–motor vehicle accidents are caused primarily by motor vehicle driver error (e.g., inattention, misjudgment, error, or faculty impairment).

Because of the number of factors involved, and the planners' inability to control them, the use of grade crossings involves real-world risk that must be evaluated. There is no simple formula that will identify the correct alternative. Value judgments consistent with the individual corridor and its elements are required. The five most important factors in evaluating grade crossings for HSR are

- Safety,
- Cost,
- HSR and highway operation,
- Environmental concerns, and
- Institutional issues.

The key subject areas are

- Safety:
  - Accident frequency,
  - Fatality frequency,
  - Injury accidents,
  - School bus operation,
  - Hazardous material carriers,
  - Long or heavy vehicles, and
  - Pedestrians.
- Cost:
  - Capital costs and
  - Operation and maintenance cost.
- Rail and highway operations:
  - Vehicle delay;
  - Emergency response time; and
  - Traffic operation including vehicle operations, capacity constraint, roadway classification, signalization, travel pattern, rail operations, and frequency.
- Environmental concerns:
  - Land use,
  - Neighborhood impacts,
  - Noise,
  - Air quality, and
  - Aesthetics.
- Institutional issues:
  - Laws,
  - Regulations,
  - Policies and guidelines,
  - Contractual obligations,
  - Local ordinances, and
  - Liability insurance.

Safety

HSR worldwide has an unblemished safety record, partly because existing HSR lines are totally grade separated. Unquestionably, HSR lines would be safest without grade crossings. Nothing less than automatic gates and signals should be considered acceptable for HSR operation. Likewise, all private crossings should be eliminated.

In addition to the direct cost of life and property, the perception of the safety of the HSR operator could have a severe impact on users' mode preference. Accidents at conventional rail grade crossings have been dramatic, well publicized, and in many cases catastrophic. Most grade crossing collisions are attributed to vehicle operator error: the driver does not recognize the crossing or the train. However, the publicity is usually unfairly focused on the railroad. Use of gates significantly reduces crossing accidents.

The probability of an HSR-automobile collision at a grade crossing is influenced by the number of motor vehicles, the frequency of trains, and the type of protection afforded. Accident frequency calculations have been developed to identify the effectiveness of different types of crossings. The existing accident rate calculations provide simple and approximate values. The U.S. Department of Transportation (DOT) accident prediction formula (*3*) combines a formula of prediction based on crossings characteristics as follows:

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$$

where

a = initial accident prediction (accidents per year at the crossing),
K = formula constant (0.001088),
EI = exposure index based on product of highway and train traffic $\left(\frac{C \times t + 0.2}{0.2}\right)^{0.3116}$ where C is annual average numbers of highway vehicles per day (total both directions) and t is average number of train movements per day,
MT = factor for number of main tracks [= $\exp(0.2912\ mt)$ where mt = numbers of tracks],
DT = factor for number of through trains per day during daylight (= 1.0 for gates),
HP = factor for highway surface (= 1.0 for paved),
MS = factor for maximum timetable speed (= 1.0 for gates),
HT = factor for highway type (= 1.0 for gates), and
HL = factor for number of highway lanes [= $\exp(0.1036h - 1)$ where h = number of highway lanes].

Applying the formula to a two-lane paved crossing with average daily traffic of 10,000 vehicles and an HSR operation of 50 trains at 185 mph would result in an accident prediction of 0.13 accident per year. (It is not known how much error is introduced by extrapolating the speed from currently normal levels to 185 mph.)

The U.S. DOT has also developed a formula for predicting the severity of a crossing accident (*3*). The probability of a fatal accident is calculated as follows:

$$P(FA/A) = \frac{1}{(1 + CF \times MS \times TT \times TS \times UR)}$$

where

CF = formula constant (695),
MS = maximum timetable train speed factor (= $ms^{-1.074}$),
TT = through trains per day factor [= $(tt + 1)^{0.1025}$],
TS = switch trains per day factor [= $(ts + 1)^{0.1025}$],
UR = urban – rural crossing factor [= $\exp(0.1880ur)$],
ms = maximum timetable train speed (mph),
tt = number of through trains per day,
ts = number of switch trains per day, and
ur = 1 for urban crossing or 0 for rural crossing.

Applying the formula to a two-lane urban crossing with 50 trains per day yields a fatality probability, given an accident, of 0.22 for a train operating at 100 mph and 0.35 for a train operating at 185 mph. (Again, it is not known how much error is introduced in extrapolating the train speed to 185 mph.)

To illustrate the potential frequency of accidents at grade crossings on a typical HSR line, assuming that all 109 estimated two-lane highways over the HSR line in the Texas study are at grade, in 1 year the probable number of accidents would be 0.13 × 109 = 14.17 and the probable number of fatalities would be 0.35 × 14.17 = 5 persons per year. (Note: A major problem with applying this formula to HSR is that it does not take into account train passenger fatalities. If train passenger fatalities were somehow accounted for in the equation, this number could rise substantially.) On the basis of 13 hundred million passenger miles projected in 1995 for the Texas corridor and an industry intercity average of 0.2 fatality per hundred million miles, the expected number of fatalities would be 0.2 × 13 = 2.6. Therefore, assuming that these probabilities are accurate, if the Texas corridor had fewer than 55 at-grade crossings ($^{109}/_{2}$), it could operate at a level of safety comparable with the industry average.

The foregoing crude estimation is not intended to be the basis for advocating grade crossings on HSR lines; it is merely an indication of what might be predicted to occur. Accounting for train passenger fatalities in these calculations would appear to make grade crossings most undesirable from a safety standpoint unless they could be protected exceedingly well to reduce the risk of accident to the lowest point possible. A more rigorous analysis of the risks and the factors affecting the frequency and severity of crossing accidents at well-protected crossings is clearly needed. The literature contains several research reports on the subject (*4–11*); nevertheless, much more study is needed. Improvements in crossing protection should be developed and tested for use on HSR systems to reduce the risk of accidents. Without such improvements it is questionable whether grade crossings are viable in high-speed territory.

Cost

The cost factors involved in evaluating grade separations versus grade crossings are capital costs and operation and maintenance costs. Two important questions are

- What are the costs associated with the crossing?
- Who will bear them?

There may be a potential for sharing grade separation costs by using highway grade crossing elimination funds to help defray the HSR system cost.

Grade Separation

In the recent feasibility study of the HSR service from Houston, Texas, to Dallas–Fort Worth (*2*), the estimated grade separation costs were

- HSR over four-lane highway: \$1.0 million
- HSR over railroad: \$1.0 million (equivalence is coincidental)
- Two-lane highway over HSR: \$0.8 million
- Four-lane highway over HSR: \$2.2 million

These cost estimates were based on the project design criteria for guideway and highway, acceptable grades, minimum clearances, and Texas Department of Highways and Public Transportation unit costs. The HSR line would be elevated at 14 of the 135 crossings. At two places in the Dallas–Fort Worth area the HSR would be elevated for a distance of more than 7 mi, and at two places in the Houston area it would be elevated for almost 6 mi. The extended elevated HSR line would be required because of the number of crossings and the vertical curve requirements of trains operating over 150 mph. Of the estimated 113 two-lane roadways elevated over the HSR, 105 were identified in the 224 mi between Houston and Dallas. The entire corridor, which occupies existing rail corridors through most of its length, passes through 10 counties and 19 intermediate cities.

Grade Crossing Protection and Maintenance Costs

The current cost of installing conventional crossing protection (flashing lights with gate arms) ranges from \$35,000 to \$50,000, and the operation and maintenance cost runs about \$2,000 per year per crossing. It is unknown what increased cost would be incurred in providing more sophisticated protection systems for HSR.

Highway Operation

The impact of adequate HRS crossings on the roadway and roadway network should be evaluated. A basic premise is that all advance warning and active devices will be provided to ensure the best quality crossing. Likewise, HSR trains should be equipped with appropriate devices and be operated so that, in the event of a stalled vehicle on the track, they can be brought to a stop (*12*).

The effects of vehicles queueing at a traffic signal during a crossing closure, and the effects on vehicles traveling on other roads, should also be analyzed. Likewise, the use of the crossing by emergency vehicles, alternative routes, and the impact of maximum delays should be evaluated.

The magnitude of the delay encountered as a result of the closure of the grade crossing is a measure of the impact on the highway. The factors involved are

- Duration of the crossing closure,
- Hourly highway traffic volume, and
- Potential train delays.

The minimum advance warning given in the *Texas Manual on Uniform Traffic Control Devices* is 20 sec (*13*). Motor vehicle travelers find any delay greater than 50 sec annoying and troublesome. However, for trains traveling at speeds in excess of 100 mph, delays would be much larger. If the braking system of an HSR vehicle traveling at 150 mph were applied at a constant deceleration of 3 ft/sec^2, it would take more than 1 min to stop the train, and the train would travel almost 3 mi. Assuming a reaction and confirmation time of 40 sec plus a control time of 50 sec (which represent the time the protective warning devices are active before a train enters and after it leaves), a minimum of 2.5 min of vehicular delay could occur. And, if, coincidentally, trains were approaching from both directions, a delay in excess of 5 min could occur.

Total delay can be estimated by the following formula (*4*):

$$D = [(T/2 + 0.10)\,N + (N/n)^2]/60$$

where

D = total delay (min),
T = duration of closure (min),
N = number of vehicles delayed, and
n = number of highway lanes.

Assuming peak-hour traffic of 1,000 vehicles per hour per direction,

$$D = \left\{\left[\left(\frac{2.5}{2}\right) + 0.10\right] 80 + \left(\frac{80}{2}\right)^2\right\}/60$$

= 28 vehicle minutes of total delay per crossing.

The results of the analysis could be compiled on a per day, per week, or yearly basis for an individual crossing or the entire corridor.

Advance Warning

Advance warning to facilitate vehicle recognition should be carefully located before the crossing. The distance from the crossing should be established on the basis of the operating speed and the physical characteristics of the roadway and the terrain. The advance warning should be located before a decision zone so that the crossing signal is not unexpected and drivers can see it in time to react. The two types of active devices are flashing signs and signal supplements. The flashing signs can indicate whether to proceed or stop (e.g., Prepare to Stop When Flashing). Strobe lights in a flashing white light can supplement a traffic control signal. This configuration is intended to draw motorists' attention in situations in which the signal is unexpected or difficult to distinguish from the lights. Appropriate countermeasures should be used to eliminate devices that detract from motorists' ability to identify and properly respond to a crossing closure.

Automatic gates with flashing lights are probably the minimum basic requirement on any highway that crosses HSR tracks at grade. The gates should be activated by timed devices. If freight trains or rail traffic other than the HSR use the tracks, the operation of the gate and flashing lights should be timed so that motorists do not wait an excessive amount of time for non-HSR trains.

The crossing should also be constructed so that pedestrians and other nonmotorized users such as bicyclists heed the warning. Devices that deter animals from entry should also be considered. An at-grade crossing is an unprotected entry and may be a particular problem where the remainder of the corridor is fenced. Animals could enter the right-of-way at a crossing and become trapped by the fencing along the line.

Mandatory stops by trucks, semitrailers, and buses may not be appropriate for HSR crossings because the potential for these vehicles to stall on the tracks is increased. Analysis may show that restricting the types of vehicles that can cross HSR tracks at grade might be worthwhile.

An important element of the operation of at-grade crossings and their active warning devices is provision of efficient and timely corrective maintenance response. Gate arms are frequently damaged; they are damaged if they descend on a vehicle proceeding through the crossing when the signal is activated or if they are vandalized. A corrective maintenance program should be established with qualified personnel within an appropriate response zone and with adequate spare parts such that any "outage" can be repaired soon after it is detected. Other forms of control might be applied in the interim, including reduction of train speeds or manual supervision of the crossing.

HSR Operation

Punctuality, reliability, and safety are all key for successful HSR operation. Strict safety measures and procedures must be implemented to avoid endangering passengers. Route protection, including induction loops, interlocking signaling, and speed monitoring, is the basis for safe operation. The nature of the technology and the speed at which the HSR operates will help determine the level of protection required.

Automatic train detection through electrical circuitry can be used to advise motorists of an oncoming train and to activate the advance warning signals and train control. The electrical circuit uses the rail as a conductor; the presence of a train shunts the circuit. The system should be designed fail-safe so that any shunt of the circuit—by vandalism, maintenance equipment, or a broken rail—will have the same effect. Standby power should be provided in the event of power outage.

Environmental Concerns

The Environmental Protection Act requires that an appropriate environmental analysis be done of any proposed HSR corridor. This would involve a characterization of the corridor and the effect of the construction and operation of the HSR on the social, economic, and environmental characteristics of the corridor. The issue of elevated versus at-grade crossings will have mixed effects. The elevated roadway or railroad will have visual as well as noise impacts. Noise can possibly be mitigated. At-grade crossings have safety impacts. These impacts must be measured against generally accepted values and evaluated.

Associated impacts including displacement of land through right-of-way acquisition and disruption of land use, community, and neighborhood activity patterns must also be considered. Reduction in economic activities and property values may also be an issue. The communities that the HSR line serves will have the direct benefit of the service as well as its construction. Those communities through which the train passes may perceive the HSR as a safety hazard, a disruption, and that the only benefit they receive is the maintenance activities. They may perceive at-grade crossings as hazardous to their traveling public. State agencies generally have the authority to establish crossings.

Institutional Issues

There is a host of institutional issues regarding the use of grade crossings on new HSR rail lines. State transportation departments and public utility commissions vary widely in their laws and regulations regarding public safety vis-à-vis grade crossings. Many local governments also have ordinances that address the speed of trains through urban and suburban areas where complete rail-highway grade separation does not exist. Liability insurance coverage (availability and cost) is another important factor to consider in evaluating the use of at-grade crossings on HSR lines (*14*).

Each proposed HSR system will have to deal with state and local laws and ordinances to determine the feasibility and costs applicable to that system. Institutional issues may very well drive the decision, not purely technological, economic, or safety considerations.

CONCLUSION

HSR around the world has an enviable safety record. The Japanese Shinkansen has operated since 1964 carrying over 2,300 million passengers without a single casualty. The French TGV Southeast Line, operating since 1981, has had a similar unblemished record. Both of these systems, however, are completely grade separated.

HSR's safety record is one of its selling points; safety should not be compromised by introducing an unnecessary risk factor. Therefore, for grade crossings to be used on HSR lines, they must be made extremely safe.

Although no one can expect a high-speed passenger rail system to have a perfect safety record indefinitely, the public will demand that HSR safety be equivalent to or better than that of existing conventional rail passenger service and comparable to that of air travel. Therefore ways must be found to improve safety at crossings.

Further research on the cost and risks of grade crossings on HSR lines is called for. The following topics are appropriate for further research:

- Innovative active warning devices,
- Highway vehicle–activated versus train-activated crossings,
- Improvements in signal visibility,
- Evaluation of driver behavior at crossings,
- Impacts of long and heavy vehicles,
- Effects of nighttime and inclement weather, and
- Determination of highway user level of understanding of crossing control devices.

Grade crossings should not be perceived as totally incompatible with HSR, but they must be carefully analyzed and evaluated before acceptance as part of HSR implementation. In the final analysis, the cost of making grade crossings sufficiently safe for use on HSR lines may approach the cost of eliminating them altogether. The cost savings versus the liabilities of not fully eliminating grade crossings must be evaluated on a case-by-case basis.

REFERENCES

1. *High-Speed Traffic on the Railway Network of Europe.* Report of the international seminar, Hanover, Federal Republic of Germany, April 12–14, 1986. Economic Research Center, European Conference of Ministers of Transport, Paris, France, 1986.
2. *Project Feasibility Report: ICE Intercity Express, Dallas-Houston.* The German High Speed Consortium; Parsons Brinckerhoff/DE, July 1985.
3. *Railroad-Highway Grade Crossing Handbook,* 2nd ed. FHWA-TS-86-215. FHWA, U.S. Department of Transportation, Sept. 1986.
4. R. C. Taggart and P. Lauria. *NCHRP Report 288: Evaluating Grade-Separated Rail and Highway Crossing Alternatives.* TRB, National Research Council, Washington, D.C., June 1987.
5. J. A. Hopkins. *Grade Crossing Protection in High Density, Passenger-Service Rail Corridors.* FRA, U.S. Department of Transportation, 1973.
6. *Rail-Highway Crossing Accident/Incident and Inventory.* Bulletin 9, Calendar Year 1986. Office of Safety, FRA, U.S. Department of Transportation, June 1987.
7. *Use of Existing Highway Right-of-Way for High Speed Rail Transportation.* Texas Transportation Institute, College Station; State Department of Highways and Public Transportation, Austin; FHWA, U.S. Department of Transportation, Feb. 1985.
8. *Rail-Highway Crossing Safety Report.* Office of Safety, FRA, U.S. Department of Transportation, July 1985.
9. R. W. Eck and J. A. Halkias. *Further Investigation of the Effectiveness of Warning Devices at Rail-Highway Grade Crossings.* In *Transportation Research Record 1010,* TRB, National Research Council, Washington, D.C., 1985, pp. 94–101.
10. W. D. Berg. Causal Factors in Railroad-Highway Grade Crossing Accidents. In *Transportation Research Record 847,* TRB, National Research Council, Washington, D.C., 1982, pp. 47–53.
11. P. Mengert. *Rail-Highway Crossing Hazard Prediction Research Results.* DOT-TSC-FRA-79-1. FRA, U.S. Department of Transportation, March 1980.
12. *Transportation Research Record 1010: Traffic Control Devices and Rail-Highway Crossings.* TRB, National Research Council, Washington, D.C., 1985, 122 pp.
13. *Texas Manual on Uniform Traffic Control Devices.* State Department of Highways and Public Transportation, Austin, 1980.
14. D. S. Glater and T. K. Mond. *Legal Effects of Use of Innovative Equipment at Railroad-Highway Grade Crossing on Railroad's Accident Liability.* Report DOT-TSC-FRA-79-19. FRA, U.S. Department of Transportation, Oct. 1979.

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