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InterCity Express: A Technical and Commercial Assessment

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InterCity Express:
A Technical and Commercial Assessment

Brian D. Sands

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The University of California
Transportation Center

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Berkeley, CA 94720

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ABBREVIATIONS

ac	alternating current
BMFT	Bundesministerium für Forschung und Technologie
BMT	Bundesministerium für Transport
cbft	cubic feet
cbm	cubic meter (35.714 cubic feet)
DB	Deutsche Bundesbahn
dB(A)	decibels
dc	direct current
DM	German Marks (DM 1=$0.67 [1991])
EC	EuroCity
ft	feet
ha	hectares (2.471 acres)
Hz	Hertz
IC	InterCity
ICE	InterCity Express
ICE-G	InterCity Freight
ICE-M	InterCity Multi-system
ICE-V	InterCity Experimental
IR	InterRegio
kmh	kilometers per hour (0.6214 miles per hour)
km	kilometer (0.621 miles)
kN	kilonewtons
kV	kilovolts
m	meter (3.281 feet)
mg	milligram (0.00022 pounds)
mi	mile
mph	miles per hour
pj	peta-joule (10-15 joules)
pkm	passenger kilometers
pmi	passenger miles
sqkm	square kilometer (0.386 square mile)
sqm	square meter (10.764 sqft)
sqmi	square mile
sqmm	square millimeter (0.039 inch)
t	ton (1000 kg)
TGV	Train à Grande Vitesse
Wh	watt hours

PREFACE

This is one of a series of reports now being produced as the first output of our study of the potential for a high-speed passenger train service in California. Each report deals with a specific high-speed train technology; it attempts an evaluation, standardized as far as available data permit, of its technical and economic viability.

Specifically, each report assesses the particular high-speed technology against a number of criteria:

1. *Technical Performance:* configuration of roadbed in terms of gradients, curvature, and construction cost; power sources; capacity and speed; capacity to integrate with existing transportation facilities.

2. *Economic performance:* traffic levels; revenues; financial appraisal and overall cost-benefit analysis; level of public subsidy required, if any.

3. *Resource consumption and environmental performance:* type and amount of energy required; impact on non-renewable resources; environmental impact, including emissions, noise, visual intrusion and effect on local communities.

The present series includes five studies. Two companion studies, on British Rail's InterCity 125 and 225 services and on Tilting Trains (the Italian *Pendolino* and the Swedish X-2000 service), will follow shortly. Thereafter, a systematic comparative analysis will be published.

The CalSpeed study will continue with preliminary route alignments, also to be produced shortly, followed by market assessments, to be completed in Fall 1992. These will bring to a close the present phase of work, which will be the subject of an overall report also to be completed in Fall 1992.

We gratefully acknowledge the support provided by the U.S. Department of Transportation and the California State Department of Transportation (Caltrans) through the University of California Transportation Center. Of course, any errors of fact or interpretation should be assigned to us and not our sponsors.

PETER HALL
Principal Investigator

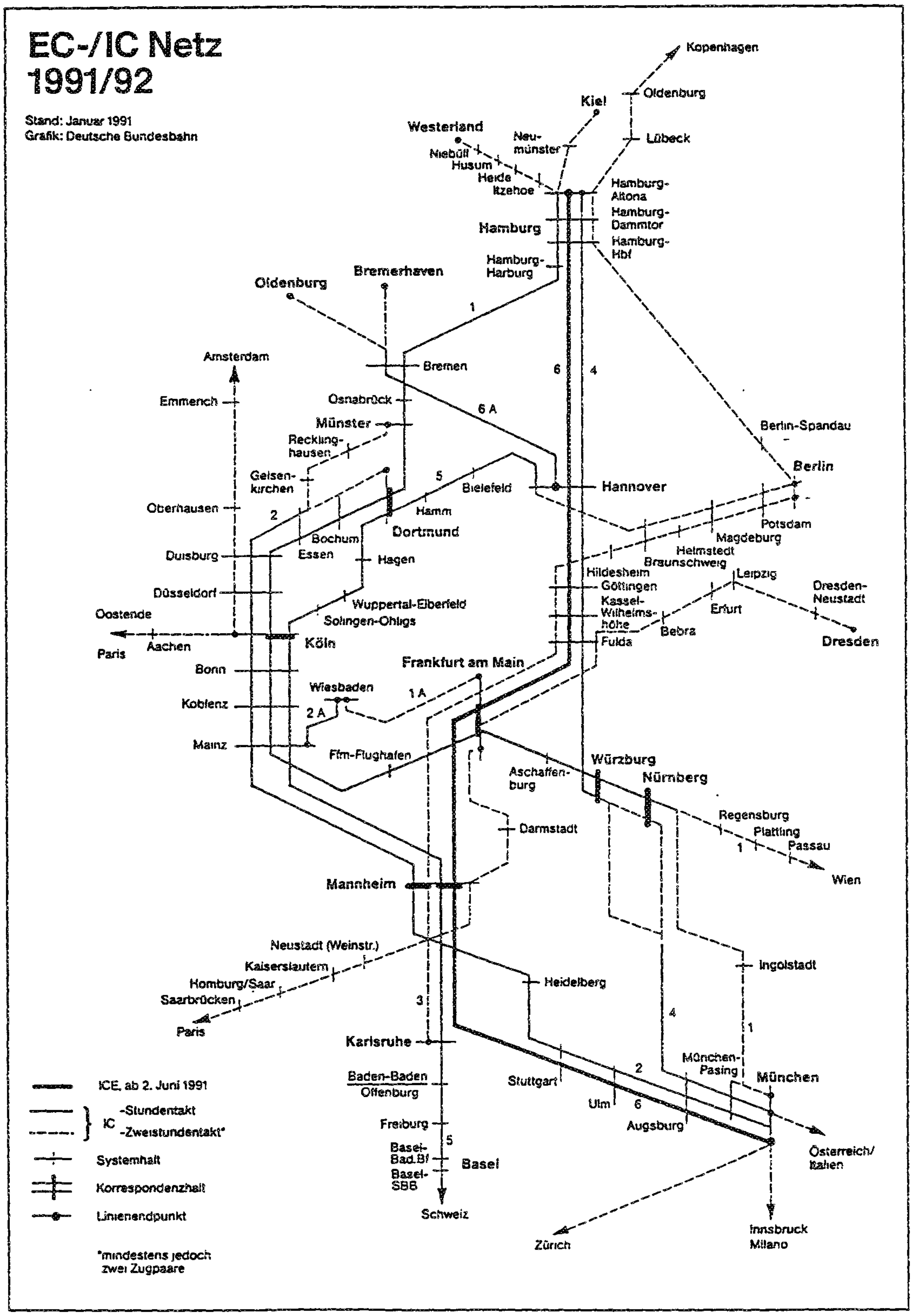
1. BACKGROUND

The German InterCity Express (ICE) is the product of a series of developments dating back to the late 1960s when the declining contribution of rail in Germany's rapidly growing transportation sector was first officially recognized. The lack of investment in rail infrastructure, rolling stock, and subsequent decline in service is evident by the drop from 16.1 percent in 1960 to 6.7 percent in 1986 of rail's share of German passenger traffic (Schnell, January 1989: 45). This was largely due to the ease and speed of automobile and air travel. The result was a program to update the infrastructure and rolling stock, improve quality and service, differentiate market segments, identify matching products and integrate services, and restructure the Deutsche Bundesbahn (DB).

The first step was a decision in 1969 to upgrade and expand the intercity rail network to allow passenger train speeds of 200-300 kmh (125-185 mph). Because most of the trunk lines dated from the turn of the century, narrow radii and steep gradients reduced operating speeds to less than 100 kmh (62 mph) on many segments. In addition, the trunk lines were overburdened relative to the network as a whole, and the post-WWII division of the country required a shift from the traditional east-west network to a north-south one. A decision was made to build several new segments, Hannover-Würzburg and Mannheim-Stuttgart, resulting in the construction of 427 km (265 mi) of new line. The line cost was DM 16 billion ($10.7 billion), with an average cost of DM 37.5 million per km ($40.5 million per mile) (Deutsche Bundesbahn, March 1991: 6; "Heavy Spending on HS Infrastructure," June 1990: 61).[1] Upgrades for 200-250 kmh (185-155 mph) operations were also made on numerous existing lines, such as Dortmund-Kassel, Würzburg-Nürnberg, and Frankfurt-Mannheim. Upgrades included laying new tracks to raise capacity, realignment of existing tracks to increase speed, improving station layout for through trains, elimination of at-grade crossings, and installation of through-the-rails cab signalling for operations above 160 kmh (100 mph). A combination of both was used on other segments, such as Nürnberg-Munich and Karlsruhe-Basel. All segments currently carry a mix of passenger and freight trains, with the exception of the new Cologne-Frankfurt/Wiesbaden segment, which will be a dedicated passenger track. The routing of this line was not finalized until summer of 1991 and it is not expected to enter operations until the mid- to late-1990s.

By the introduction of ICE operations on June 2, 1991, the German high speed rail network was 1,043 km in length, with plans to expand to 2,000 km by the end of the decade (Deutsche Bundesbahn, 1991: 15). Currently, there is a single ICE line, Hamburg-(Altona, Damtor, Haupbahnhof)-Hannover-Göttingen-Kassel-Fulda-Frankfurt-Mannheim-Stuttgart-Ulm-Augsburg-Munich, and six InterCity lines (see Figure 1). The total route length between Hamburg and

Figure 1. Map of ICE and IC Network.



Munich is 950 km (590 mi) with the following segment distances: Hamburg-Hannover, 185 km (115 mi); Hannover-Kassel, 144 km (90 mi); Kassel-Frankfurt, 193 km (120 mi); Frankfurt-Mannheim, 79 km (49 mi); Mannheim-Stuttgart, 107 km (66 mi); and Stuttgart-Munich, 242 km (150 mi) (Thoma, 1991). An alternative route via Fulda-Würzburg-Nürnberg-Ingolstadt-Munich is scheduled for introduction in the fall of 1991 and will make the ICE even faster between the two end points. Eventually, DB plans to have 10 or 11 intercity lines, with the ICE operating on all but one of these ("InterCity Revolution," June 1990: 36). The new dedicated Cologne-Wiesbaden/Frankfurt line will receive ICE service at speeds up to 300 kmh (185 mph) when completed in 1997/1998. The first international ICE route, Mannheim-Offenburg-Freiburg-Basel/Zurich, is scheduled to enter service in 1992/1993. The second international ICE route is likely to be Cologne-Aachen-Brussels-Paris/London, slated to begin upon completion of upgrades along the route in the mid- to late 1990s.

The second step toward a German high speed, intercity rail network was the improvement of rolling stock. Higher levels of quality and passenger comfort were introduced with new rolling stock in the 1970s when the InterCity (IC) and EuroCity (EC) began providing hourly service between major German cities and international destinations. However, significant technological improvements were not made until research began in 1982 on the InterCity Experimental (ICE-V). By 1985, the InterCity Experimental began to make public test runs and went on to set the then world steel-wheel-on-rail speed record of 406.9 kmh (252.7 mph) in May 1988.

A total of 25 InterCity Express trainsets were available for use at the introduction of service on June 2, 1991. By the end of 1991, 16 more sets will be available, followed by an additional 19 before the end of 1993 ("Beyond the IC-Express," 1991: 299). The total cost of the first 60 trainsets is DM 2.95 billion [1990] ($1.98 billion) , or DM 49.2 million ($33 million) per trainset ("InterCity Revolution," June 1990: 35). Each trainset is capable of carrying 673-694 passengers, depending on configuration. ICE trainsets capable of multi-system operations will begin with the introduction of service to Switzerland. Work is also underway on the InterCity Multi-system (ICE-M), a trainset capable of operations on multiple rail networks outside of Germany, such as in France (SNCF), Belgium (SNCB), The Netherlands (NS), and perhaps Britain (BR). The ICE-M is likely to be introduced with service along the Cologne-Brussels-Paris/London route.

The third step was to take advantage of the previous two steps, thereby providing better intercity rail service. In the late 1970s, the InterCity (IC) provided hourly service between major German cities along four major routes with 157 trains daily. By 1988, the IC network had been expanded to eight lines and 325 trains daily (Klein, 1991: 5). DB's market strategy was designed to build on the strengths of rail service: city-center to city-center service, speed, price, comfort, and reliability. Brand image—that is, product differentiation— and market segmenting were considered critical. However, IC service continued to suffer from a reputation for long travel times and a poor on-time record relative to air or auto travel. Introduction of the ICE is designed to build on the advantages of high speed rail: reliability, travel time, and service. The ICE closes a hole in the German rail network, building on the base of local and regional networks (S-Bahn, InterRegio, and IC), providing a competitive link between cities, and eventually to expand to a European high speed rail network. The motto adopted for the ICE is "Twice as fast as the auto—half as expensive as air." It has also initiated a major change in German rail pricing philosophy; namely, the switch from the traditional flat rate per kilometer travelled to a rate based on competing modes of travel, travel time, and period of travel.

A number of key actors have contributed to the restructuring of the German rail system and the development of the ICE. The Federal Ministry for Research and Technology (BMFT) provided financial backing for the IC and is also providing funding for the competing rail system, the Transrapid Maglev. The Federal Ministry for Transportation (BMV) oversees the development of a national transportation plan every five years and also provides funding for major research projects such as the ICE. Obviously, the Federal Railways (DB)— the national owner and operator of the railway system in western Germany—had a large stake in the design and implementation of the ICE. Deutsche Eisenbahn Consulting (DEConsult), a subsidiary of the DB, provided technical support and planning for the ICE, as well as coordinating international projects. Finally, a number of very large German engineering companies worked on the development of the ICE and continue to do so with the ICE-M, including AEG, ABB, KraussMaffei, Krupp, Siemens, and Thyssen.

In addition to actively pursuing the development of the ICE in Germany, including plans to extend the system to the new states, DB is exporting its high speed rail technology and knowledge. A bid of $6.7 million was made for the proposed 1,000 km Texas high speed rail system linking Ft. Worth, Dallas, Houston, and San Antonio. This lost to Morris-Knudsen's $5.7 million bid to use TGV technology ("Germany Powers Spanish HS Line," 30 May 1991). DB is currently building the power supply system for the new Spanish rail link between Madrid and Seville, which eventually will provide high speed service between the two cities.

2. INFRASTRUCTURE

Infrastructure is the first step in providing a high speed rail system and requires the most planning and coordination. Plans made in the early 1980s called for a German high speed rail network of 2,000 km (1,242 mi) to allow speeds of 200-250 kmh. These plans were integrated into the 1980 and 1985 National Transportation Plan, a national planning document on major transportation plans in Germany. It is updated approximately every five years, with the next update scheduled for release sometime in 1992. Germany's recent reunification has forced the expansion of these plans and may eventually lead to 4,000 km (2,500 mi) or more of high speed lines in the next 20 to 30 years. These plans are currently in review with no definitive date of finalization set.

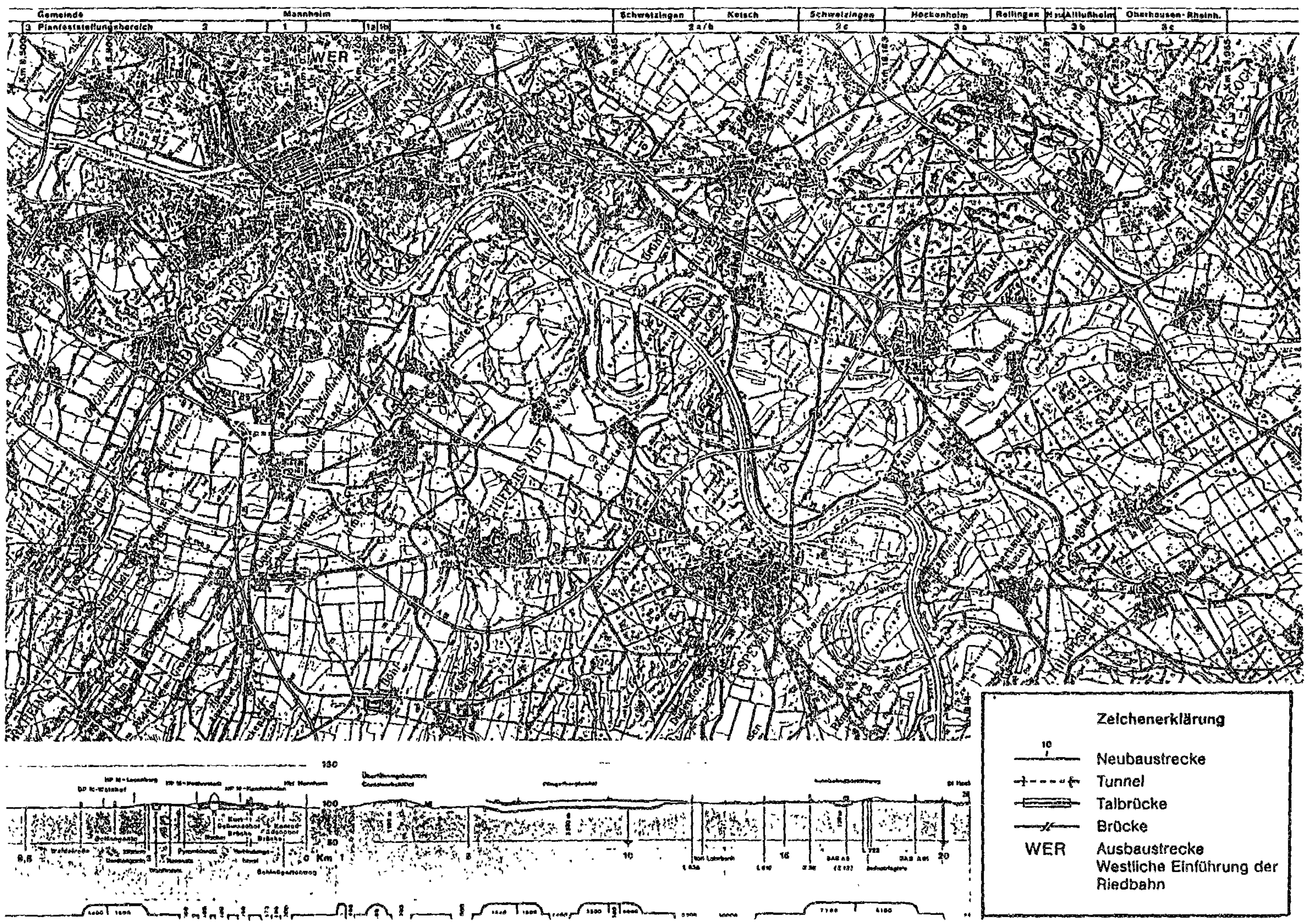
Alignment

The environmental movement in Germany is very strong and has a significant impact on all planning elements—from routing to construction— as exemplified by the two new routes. After first being proposed in 1969 and receiving a cost-benefit analysis of 1:4, they suffered repeated delays during planning and into construction, eventually entering operations in 1987/1988. Wherever possible, new routes are within or parallel to existing rail or autobahn right-of-way in order to improve design, reduce impact, and avoid planning and construction delays. Examples of this are shown in Figure 2, with a section of the new 100 km (62 mi) Mannheim-Stuttgart line. Additionally, in order to minimize impact on the surrounding environment— be it natural or man-made—as well as to reduce gradients and curve radii, very liberal use is made of tunnels, cuttings, embankments, viaducts, and bridges. For example, on the new 327 km (203 mi) Hannover-Würzburg line, 36 percent is in tunnels, 28 percent in cuttings, 25 percent on embankments, and 11 percent on bridges or viaducts ("Heavy...," 1990: 63). It should be noted that the geography of this terrain has hills 200-500 m in height.

Track

Upgrading old lines has priority over new line construction; approximately 80 percent of the 2,000 km (1,242 mi) high speed network planned by the year 2000 will be upgrades. This is done for economics, environmental impact, and efficiency reasons. Upgrading typically requires relatively simple changes to allow for operations at 200-250 kmh (125-155 mph), such as straightening route alignment, adding tracks and sidings, replacing at-grade crossings, improving station layouts for through running, improving track conditions, and upgrading signalling. Overall, it is cheaper, less damaging, and more efficient to upgrade existing lines than to build new ones. However, where upgrades are not possible or are inefficient, new lines are being built. New lines may be necessary due to poor or nonexistent alignments and large population centers along the route. The two new lines total 427 km (265 mi), containing 970 km (602 mi) of tracks, including ten sidings for passing (Reimers, 1991: 29).

Figure 2. Routing: Mannheim-Stuttgart Line Section



Track design parameters are constrained on both the new and upgraded segments because freight and passenger traffic share most of the Hamburg-Munich route. The ruling grade is currently 3 percent, allowing a 1,200 ton freight train to be hauled by a single 5,600 kW locomotive. Theoretically, the maximum gradient possible is 12.5 percent (Reimers, 1991: 19; Kurz, 1990: 441). The minimum curve radius should be 5,100 m (16,733 ft), although 7,000 m (22,967 ft) is preferred for maintenance reasons (Reimers, 1991: 19). On the future Cologne-Frankfurt line, which will be a dedicated ICE track, the maximum gradient will be 4 percent and the minimum curve radius will be 3,250 m (10,663 ft), with an overall design speed of 300 kmh (186 mph). However, on the future Nürnberg-Ingolstadt segment, which will have mixed passenger and freight traffic, the maximum gradient is 2 percent and the minimum curve radius is 4,000 m (13,125 ft), allowing a maximum speed for passenger trains of 250 kmh (155 mph), and a maximum freight train speed of 160 kmh (100 mph) ("Heavy...," 1990: 62-63).

The standard track formation width is 13.7 m (45.0 ft) and the minimum track center-to-center width is 4.7 m (15.4 ft) (see Figure 3). Conventional ballast is used, except in some tunnels which have a concrete slab base. Concrete slab base may be used more extensively in the future. Concrete monobloc sleepers (B 70) are overlain with continuously welded rail (UIC 60).

Earthworks/Tunnels/Bridges

Along the two new lines, nearly 100 km of embankments and 119 km of cuttings were made, requiring the movement of over 86 million cubic meters of earth (Deutsche Bundesbahn, "21 Jahre Arbeit sprengten die bisherigen Dimensionen," June 1991: 15; Reimers, 1991: 29). Cuttings and embankments are designed so that the slopes blend in with the natural environment, with excess spoils relocated to a nearby location and incorporated into the local environment ("Railway Tunnels and the Environment," 1989: 5).

The two new lines have a total of 76 tunnels, with a combined length of 152 km (Reimers, 1991: 29). Double-lined, single-bore tunnels were constructed, with a cross-section of 145 sqm (1,561 sqft) (see Figure 4). Construction of the tunnels required the removal of 38 million cbm (1.357 billion cbft) of earth, 12 million of which were incorporated in the construction of the lines (Deutsche Bundesbahn, "21...," June 1991: 15). Tunnel construction techniques were carefully evaluated before finally going with conventional driving methods– using blasting or excavation– as opposed to the use of full-section cutters. This decision was made based on the difficult geological conditions encountered along the routes. Excavation proceeds in three steps due to the large cross section: first the roof is driven, excavated, and stabilized with shotcrete and anchor holes; second,

Figure 3. Track Cross Section

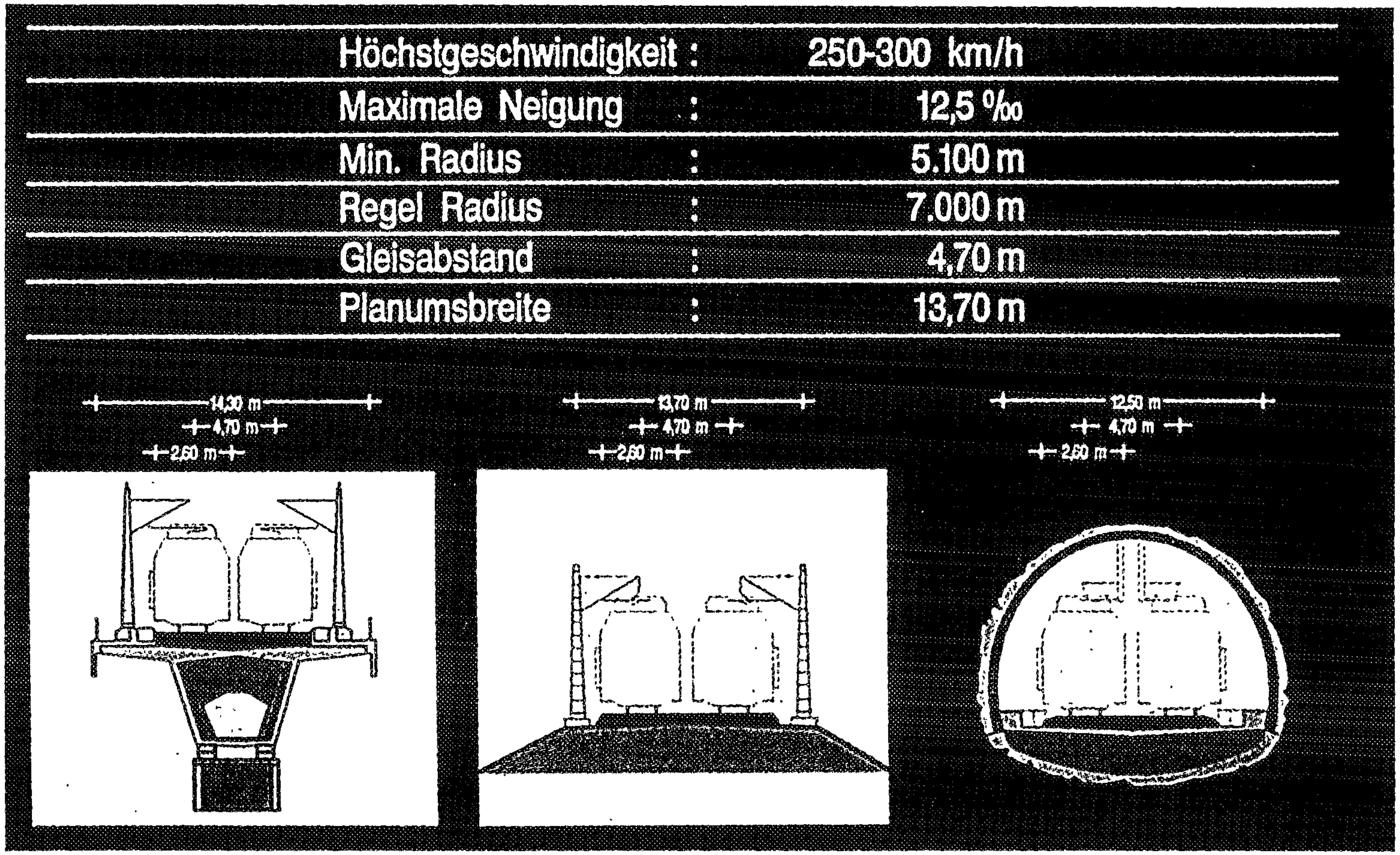
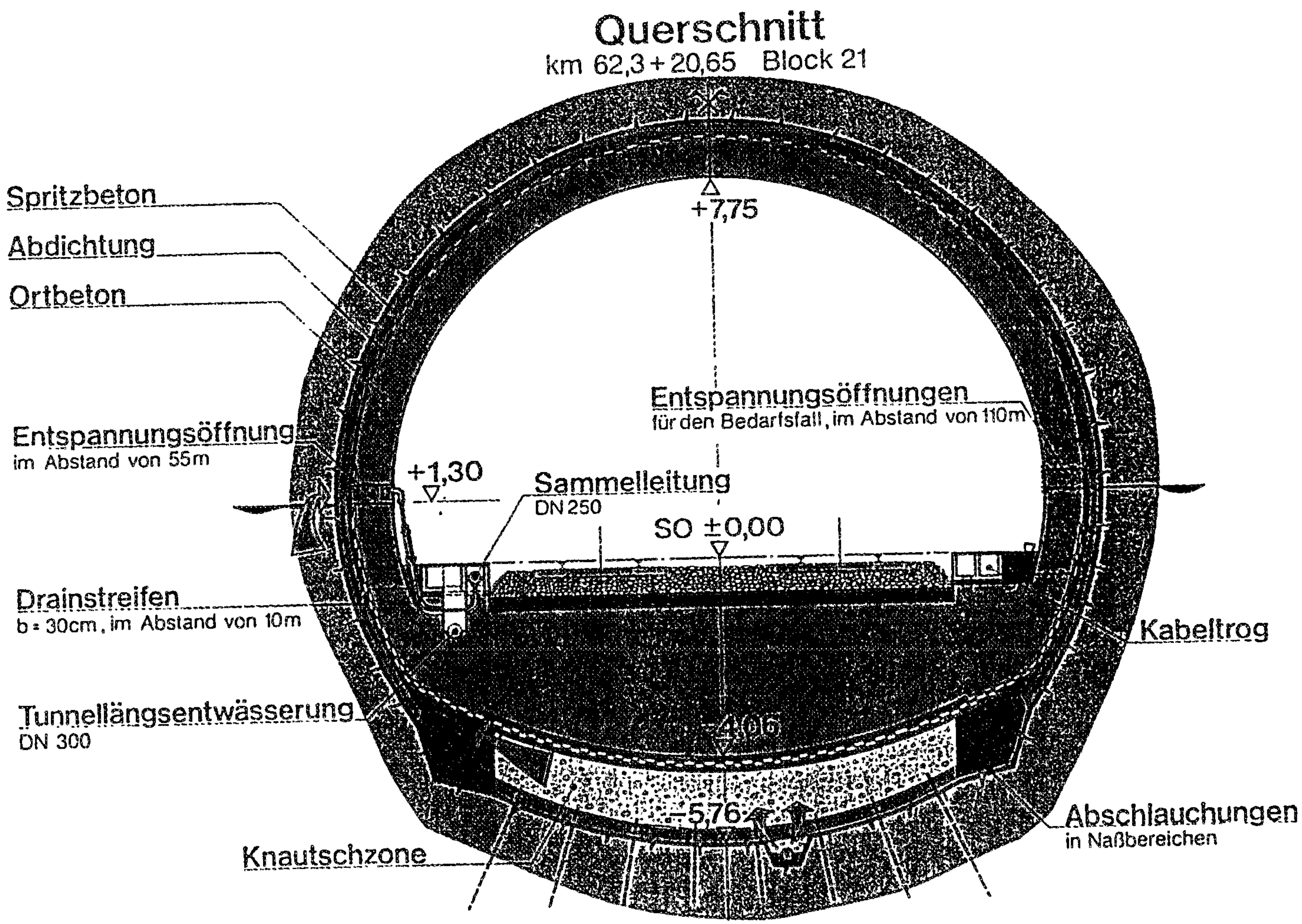


Figure 4. Tunnel Cross Section.



the bottom part is treated in a similar manner; finally, the bench and floor are excavated, and a concrete footing and floor laid. Steel formwork and a waterproof membrane are installed before the inner lining. Pumped concrete forms the inner lining between the formwork and rock (Leichnitz, 1987/1988: 14).

A total of 384 bridges, with a combined length of 35 km, are used on the two new lines (Reimers, 1991: 29). Mixed traffic creates a significant bridge design and construction problem due to the high, horizontal loads generated by freight trains. The Rombach Bridge, located near Fulda, is the tallest bridge; it is 100 m (328 ft) in height and crosses a valley 1,000 m (3,281 ft) wide. It uses an A-trestle in the center to dissipate horizontal loads generated by braking. The arch was completed using stabilizing cables to hold the two halves in place as they were being concreted; they became self-supporting upon meeting in the center. The bridge decks were constructed with the use of a pre-stressed concrete launching device for the first time (Leichnitz, 1987/1988: 14).

Near Würzburg, the Main Valley is crossed by a 1,300 m (4,265 ft) bridge, with an evenly pre-stressed arch of 162 m (531 ft) spanning the Main River itself. The local planning authority demanded a very fine structure to minimize the visual impact on the valley, requiring the arch to be very tight and constructed as a single structure. This presented problems because the temperature of concrete is very high when poured in large sections and subject to cracking. An innovative technique was used to pre-cool the concrete during mixing, and then it was poured into the formwork (Leichnitz, 1987/1988: 13-14).

A total of 2.4 million tons of cement were used to make the necessary 7.1 million cubic meters of concrete used on the two new lines (Deutsche Bundesbahn, "21...," June 1991: 15).

Signalling and Power Distribution

On the new, upgraded, and main lines, a computer monitoring and signalling system is used. The system knows which trains should be where at what time, monitors their progress along the line, and adjusts the schedule according to delays and changes. The system cuts down the need for visual and radio monitoring of operations (Deutsche Bundesbahn, March 1990: 7).

All trains operating at speeds of 160 kmh (100 mph) or more in Germany have inductive train control, allowing signalling through the rails and automatic train control. Drivers have in-cab displays with information relative to their route, including allowable and actual speed, braking distance to next restriction, signal aspect, their schedule, and their performance relative to the schedule (Deutsche Bundesbahn, *Moderne Strecken und schnelle Züge- ein Konzept für die Zukunft:* 16).

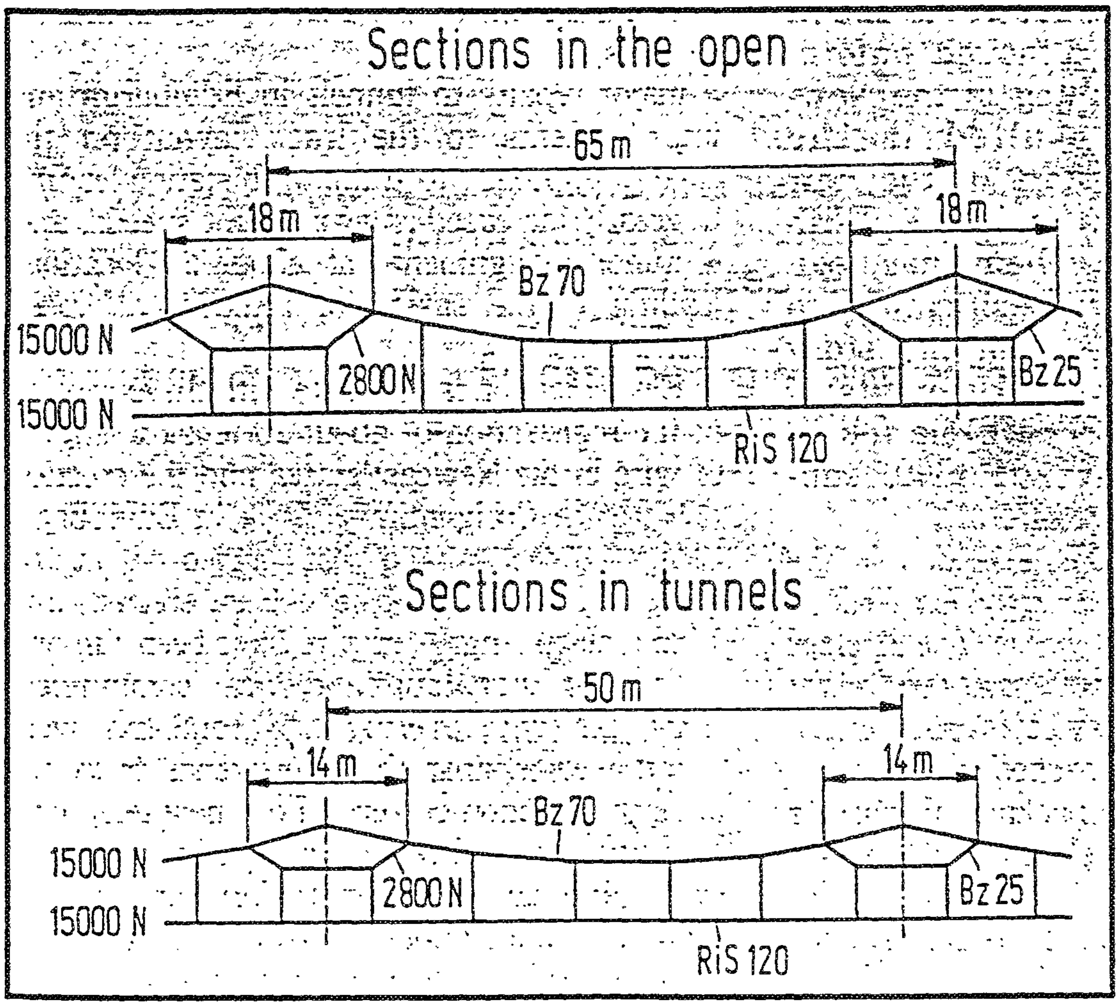
Power distribution is done via a catenary suspended under tension above the track, carrying a voltage of 15kV, or 16-2/3 Hz. DB is installing the power line for the new TGV-style train in Spain, which will run between Madrid and Seville. Except for the voltage, which is 25 kV 50 Hz along the Spanish line, the equipment and layout is identical to the new and upgraded lines in Germany (see Figure 5). The catenary has a contact wire and messenger wire, with stitch wire at the supports. Span lengths are 65 m in the open, reducing to 50 m in tunnels, with corresponding system heights of 1.8 m and 1.1 m, respectively. Stitch wire lengths are 18 m and 14 m, respectively, and gives nearly the same tension at the span supports and midpoints. The contact wire has a cross section of 120 sqmm and is made of copper alloyed with 0.1 percent silver. The messenger wire has a cross section of 70 sqmm and is made of bronze. Tensile strength is 15 kN to allow for high speed operations and wear. Automatic tensioning devices adjust cantilever height for changes in temperature and work over line sections 1200 m in length. The catenaries are all aluminum, mounted on pre-stressed concrete masts that are pile-driven or have concrete pier foundations. Aluminum feeders strung along the masts return the power current to the rail to avoid short circuits as well as parallel limit signalling and communications interference ("Germany...," May 1991: 33-34).

Stations

Stations that allow trainset operations and also function well for passengers are a critical part of the ICE system. With the exception of the new passenger station at Kassel-Willhelmhöhe and the new ICE workshop at Eidelstedt in Hamburg, this has involved remodelling existing stations both to accommodate ICE operations and to raise the surroundings to ICE passenger standards. The former is a precursor to ICE operations, while the latter is considered critical part of DB's marketing program to attract and retain ICE passengers.

Power line and track improvements were made into or through stations, usually as a part of general line upgrades or new construction. The ICE's long trainset length, 400 m (1,300 ft), required the extension of platforms in many stations. A series of changes was also made to improve image and passenger information at existing stations, including the following: more visible and exact passenger information systems (electronic schedule boards, signage); increased passenger access to platforms (closer location, removal of equipment, escalators, elevators); improved cleanliness of facilities, including faster trash removal from trains and platforms; better

Figure 5. Catenary Layout.



SPAN lengths are 65m long in the open and 50m in tunnels (above). Special steel weights are used for tensioning the catenary in tunnels because of space constraints (right).

lighting; and use of distinctive materials and designs (Schroer Managementberatung, March 1990; Schroer, January 1990). Many of these changes parallel a larger program to improve train stations throughout Germany, which is aimed at improving the general image of rail and the level of services provided at stations. A number of stations have received major renovations recently, such as the Hamburg-Hauptbahnhof, although these were not directly connected with the ICE.

The Kassel-Wilhelmshöhe station is the only new ICE passenger station. It is also the first new passenger train station located in a fairly large German city constructed since WWII. It was built primarily to serve ICE passengers, although numerous IC and InterRegio trains call there. The station is actually located on the site of Kassel's former local train station, approximately 3.5 km (2.2 mi) from the downtown, where Kassel's main train station was located. In the early 1970s, its 213,000 residents were served by only two IC trains daily (Nose: 134; Klotz, 1987). When proposals for alignments of the new train lines were first made in the early 1970s, Kassel wanted the line to be taken underground through the city, with the ICE station located underneath the existing main station. By 1980, it was realized that this was prohibitively expensive and that the local train station was the better choice.

The first of three architecture competitions for the Kassel-Wilhelmshöhe station was decided in 1982. The first of three construction phases began in 1984 with the removal of the small existing station. After the introduction of numerous changes, including two additional architecture teams and their designs, the station was completed in time for the commencement of ICE operations in June 1991. It is an architecturally distinct structure which has come under some criticism for design but suits its function fairly well (Langer, July 1991: 290; Meyhöfer: 27).

The station is essentially a bridge crossing the tracks, with a lid extending out and ramping down to the tracks (see Figure 6). The bridge across the tracks on which the station is located is 340 m (1,115 ft) long and 80 m (262 ft) wide in the middle, including space for a roadway, a transit right-of-way, the entrance driveway for transit vehicles, and the station lobby (Langer, 1987). The entrance driveway gives mass transit vehicles priority, with four light rail lines, seven bus stops, and 15 taxi stands located in front of the station. In addition, a bus parking lot is located immediately to the west (Nose: 140). Automobiles are relegated to two side ramps providing access to two parking decks, with drop-off locations behind the station lobby and one story over the train platforms, each 140 m (459 ft) long and 40 m (131 ft) wide in the middle. In between the station lobby and the parking lots are ramps that are 80-100 m (262-328 ft) long and 30 m (98 ft) wide, which descend to the train platforms. There are four train platforms, each 420 m (1,378 ft) long and 19 m (62 ft) wide, serving two tracks each. The western two platforms serve ICE and IC trains; the eastern two platforms serve InterRegio and S-Bahn trains; and two additional tracks

Figure 6. Kassel-Wilhelmshöhe Station.

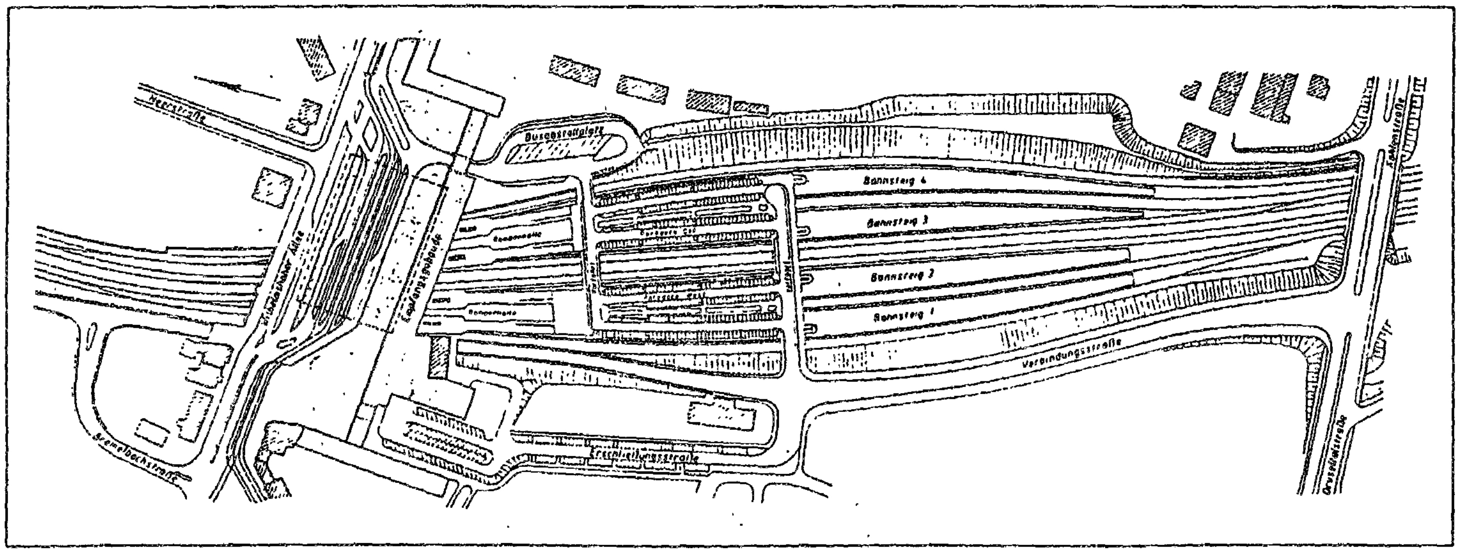
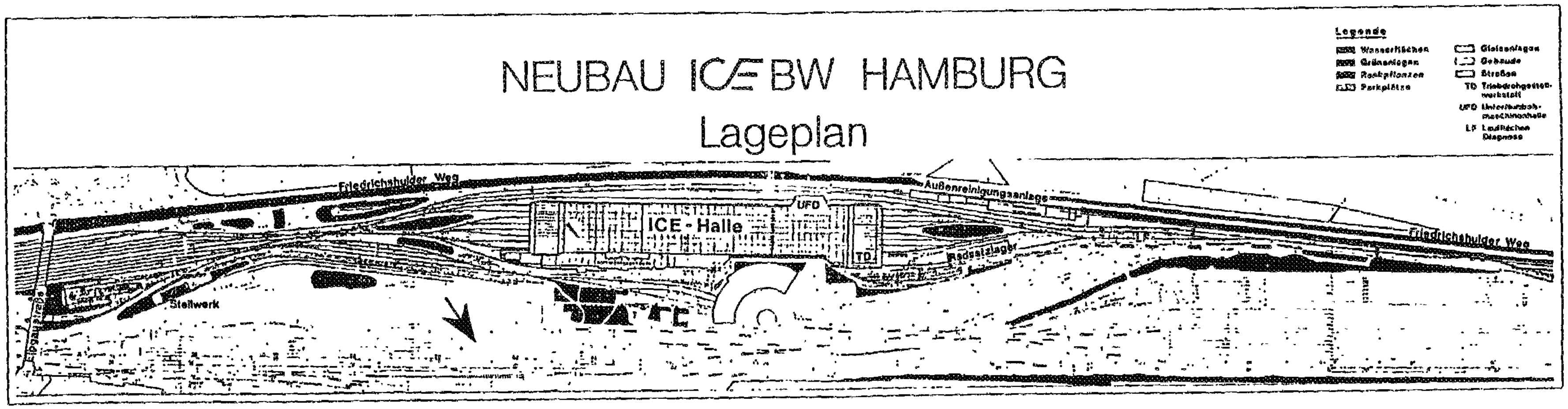


Figure 7. ICE Workshop at Eidelstedt in Hamburg.



between the middle platforms are for freight trains. The whole facility is surrounded by sound-absorbing walls and general landscaping. Construction required reconfiguring track positions 46 times and was extremely complicated due to the almost continuous design changes (Klotz, 1987).

The other completely new facility constructed for the ICE system is the Eidelstedt workshop in Hamburg. It is an extremely modern facility, designed exclusively to serve the ICE fleet, and reducing turnaround times to one hour. In addition, the facility allows trainsets to be in operation up to 20 hours daily ("State...," January 1991: 27). It is located 8 km (5 mi) from the end-train station Hamburg-Altona on the former site of a freight yard. The heart of the facility is the workshop –430 m (1410 ft) long, 65 m (213 ft) wide, and 13 m (42.6 ft) high– with eight tracks elevated at 2.4 m (7.9 ft) (see Figure 7). There are three working levels, the lowest of which is for the maintenance of the moving systems, with 56 removable track sections provided to facilitate wheel and bogie repair. The second level is for the maintenance and repair of train bodies and interiors. The third level is for the maintenance of train roofs. The facility includes all the necessary tools, including massive cranes for removal of car bodies and motors. A neighboring 250 m (820 ft) long building houses tools, parts, and offices for the 600 workers. Nearby is a 210 m (689 ft) long automated washing facility for the ICE, which uses 70 percent recycled water. Construction of the facility required moving 60,000 cbm of earth, 45,000 cbm concrete, 7,500 tons steel, and 16 km rails, in addition to the laying of 60 track segments (Deutsche Bundesbahn, June 1989).

3. ROLLING STOCK

The invention and utilization of new technologies has been a prerequisite to the production of high speed rolling stock. The ICE trainset uses innovative technology in every aspect of its production and operations. Such innovations include new suspension systems, regenerative braking, integrated microprocessor control, and a fiber-optic communications and control network. Ongoing research into new technologies and designs continue to improve rolling stock, allowing for faster speeds and more efficient operations.

Trainset[2]

Twenty-five trainsets were available for the commencement of operations in June 1991. An additional 16 trainsets were scheduled for delivery by the end of 1991, with 19 more to follow in 1992. The fleet of 60 is expected to be able to meet all of Germany's north-south flows for the time being, and will be based at the ICE workshop at Eidelstedt in Hamburg. Future trainsets will be based in Munich and Frankfurt-am-Main. Table 1 summarizes the specifications of an ICE trainset.

The ICE is easily recognizable by its sleek white body, mirrored windows, and distinctive red stripe. Vehicle surfaces are aerodynamically designed to reduce resistance, including flush-mounted windows and doors, and almost complete enclosure of the trailer car underbodies. This also serves to reduce the generation of pressure waves in tunnels, which are reduced to comfortable levels for passengers by pressure-resistant doors, gangways between cars, air conditioning systems, and toilets.

Table 1
ICE Trainset Specifications

Formation:	2 power cars, 11-14 trailers
Gauge:	1.435 m
Voltage:	15 kV, 16 2/3 Hz ac
Rated output:	9.6 mW (4.8 mW + 4.8 mW)
Tractive effort:	200 kN (100 kN + 100 kN
Trainset length:	410.7 m
Height:	3.84 m (4.295 m restaurant car)
Weight:	880 tons
Bogies:	2 per vehicle, with 2 axles/bogie
Wheel arrangement:	Bo'Bo'
Ruling grade:	3%
Crew:	2 Drivers, 1 Fitter 1 Senior Conductor, 3 Assistant Conductors Catering Staff
Acceleration:	0-100 kmh: 66 seconds 0-200 kmh: 200 seconds 0-250 kmh: 380 seconds
Braking:	250-0 kmh: 4,820 m

Microprocessors are used throughout the trainset for electronic control and supervision. The system is divided into four levels: train operation, train control, vehicle control, and subsystem control. Train operation controls are the inputs and master settings entered by the driver or wayside control devices– such as those connected to route control centers– to allow automatic train operations. Train control includes driving and braking operations– such as maximum speed, tractive effort, and braking effort– in addition to central door management, interior lighting control, and passenger information distribution. The vehicle controller coordinates operations within each car, as ordered by the train control system, including traction, braking, doors, lighting, air conditioning, and passenger information. The subsystem controllers monitor each subsystem for compliance and run diagnostics. The systems are designed to be redundant, self-monitoring, and self-repairing. A subsystem to trainset level diagnostic system continuously monitors systems for compliance and problems, notifies drivers and conductors of any problems found, and may signal maintenance facilities to allow preparation of equipment for repairs.

A trainset-wide, high-performance, digital data-transmission network is necessary to ensure smooth tractive and braking operations, particularly the coordination of the power cars which are nearly 400m apart. The ICE utilizes two fiber-optic networks running the length of the trainset to accomplish this task. The fiber-optic network alleviates concerns about electromagnetic interference, temperature extremes, shocks, and vibrations, and allows the system to be integrated into the automatic coupler. One fiber-optic network connects the two power cars, while the other connects each vehicle control center to the train control system. An additional, conventional electronic system is also provided in case of failure of the fiber-optic network. Partial failures, such as with one trailer, require switching to the conventional system only for that portion of the network.

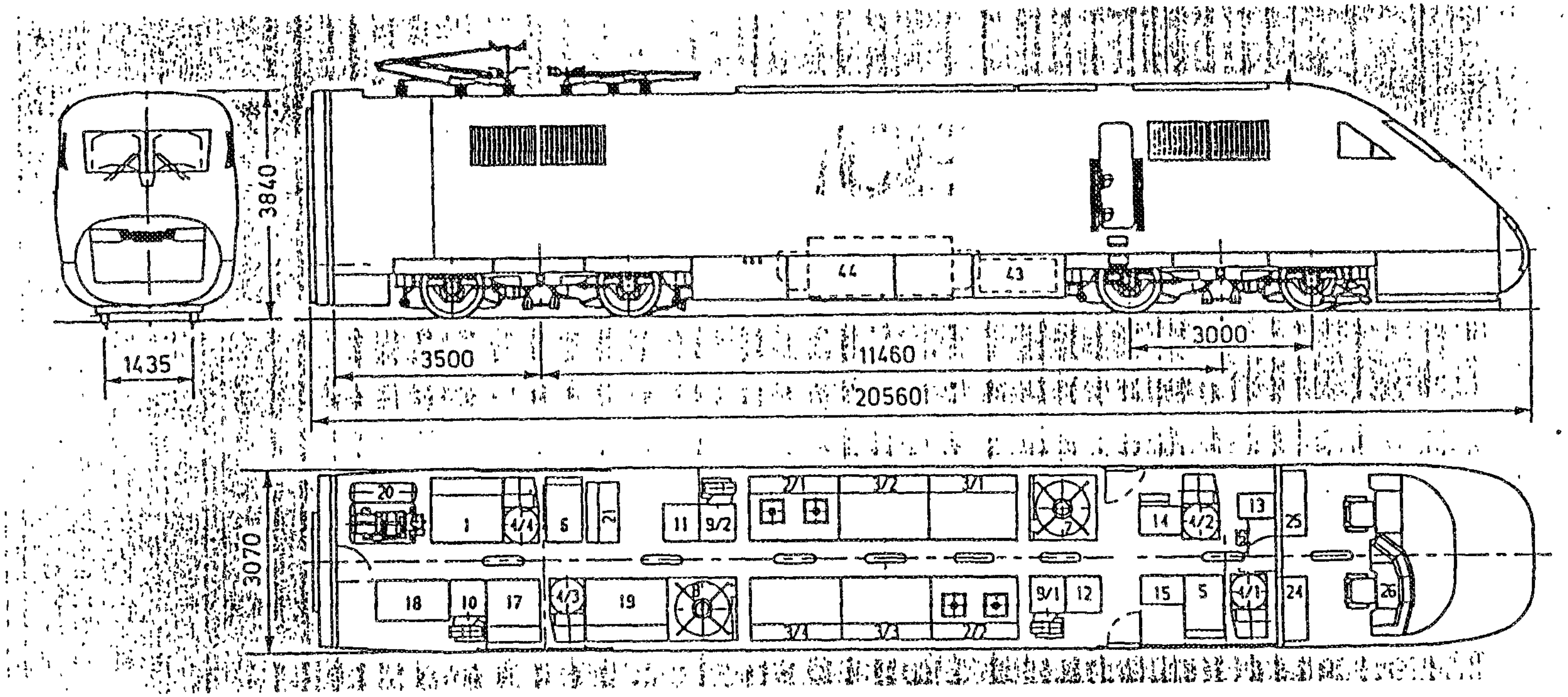
Power Car[3]

Table 2 summarizes the technical data for an ICE power car, with Figure 8 detailing its layout. Two power cars are used per trainset, one at each end. The power car frame and body are made of steel, with an aerodynamic design to reduce resistance. Due to the amount of equipment and need for quick maintenance, the underbody is not aerodynamically treated, although fairings

Table 2
ICE Power Car Specifications

Model number:	401 DB
Height:	3.84 m
Width:	3.07 m
Length:	20.56 m
Weight:	77.5-80 tons, 19-20 tons/axle
Wheel radius:	1.04 m (new) - 0.95 (used)
Axle spacing:	3 m
Tractive axles:	4
Motors:	4 asynchronous three-phase, 4-pole, forced induction, GTO thyristors, motoring and regenerative operations
Rated output:	4.8 mW
Max.tractive effort:	200 kN
Brakes:	mechanical: 2 solid discs/tractive axle, regenerative, pneumatic
Pantograph:	1
Max. speed:	250 (280) kmh

Figure 8. Power Car Layout.



1. Equipment layout in IC Express

1	=	15 kV supply
2/..	=	Capacitors for series resonant circuit
3/..	=	Main converter unit
4/..	=	Traction motor fans, motor chokes
5,6	=	Bridging contactors, balancing chokes, electronic unit
7,8	=	Oil cooler with fan
9/..,10	=	Converter units for auxiliaries
11/12	=	Electronic traction control
13	=	Optical fibre equipment, train control
14	=	Protective relays, deadman control, climate control, central distance-speed control, automatic motoring-braking control, diagnostics with automatic train preparation
15	=	Continuous inductive ATC, inductive train protection
17	=	110 V control switch board
18	=	Train busbar, public address system
19	=	Auxiliaries control, battery charger, fuses
20	=	Compressed air rack
21	=	Brake panel
24	=	Annunciator panel, refrigerator
25	=	m.c.b. panel, graphic timetables, fire extinguishers
26	=	Driver's console
43	=	Battery
44	=	Main transformer

are used on the nose. The pantograph is the only piece of equipment which rises above the smooth body of the train. It has an aluminum pan head with a carbon contact strip to ensure even contact and reduce wear. Each power car in a trainset raises its own pantograph for operation. Power cars travelling to Basel/Zurich in 1992/1993 will have two pantographs, allowing operation on 1.5 kV dc lines.

The traction concept is designed to transfer as much mass of the drive unit (motor, gear-box, transmission system) as possible from the bogie to the power car body. Two-thirds of the vertically acting mass is transferred to the body and only one-third to the bogie frame. This, combined with the use of hollow axles, reduces the weight of ICE traction bogies to half of that of conventional bogies. The end result is increased running stability, higher operating speeds, faster acceleration, low lateral track loads, and reduced track/wheel wear. Bogies are conventional, although air-sprung bogies are under experimental operation. Although air-sprung bogies appear to give a better ride and to be quieter than conventional bogies, they increase costs by approximately 10 percent and are not considered worth it at this time. However, they are probably necessary for operations at 350+ kmh (215+ mph) and research into their use for the ICE-M is continuing.

The static axle load is 19 tons (20 for non-GTO thyristor power cars, which are no longer in production), as compared to 17 tons for the TGV, widely considered the European standard. However, the DB does not use static load as a criteria, using dynamic wheel-load instead. The result yields no difference in the dynamic wheel load between the ICE and TGV to 280 kmh (174 mph), the maximum speed to which comparative studies have been made. The DB plans to build a number of trainsets with a 17-ton static axleload to prove it do so.

There are two braking systems on the ICE: regenerative and electro-pneumatic. Regenerative braking is accomplished with the power bogies by using the asynchronous three-phase drive motors to generate electricity which is then stored for later use. It is designed to regulate deceleration as economically as possible and reduce conventional brake wear. In addition, electro-pneumatic brakes act on solid (non-ventilated) discs, two per power car axle and four per trailer car axle, and control the regenerative braking operations. Eddy-current brakes were successfully employed on the InterCity Experimental, reducing stopping distances from 2,000 m (6,562 ft) with normal brakes to 1,200 m (3,937 ft) at 200 kmh (124 mph). However, signalling was disrupted, except on those lines with special modifications. They are considered necessary for operations over 300 kmh (186 mph), with research continuing on the ICE-M.

Automatic train control or driver control is possible, with the latter mostly done only when entering and exiting stations. The driver control panel has two video monitors and a number of display panels. The first monitor displays train control information, such as speed and tractive and braking power, as well as line information, such as allowable and actual speed, braking distance to next restriction, and signal aspect. The second monitor displays complete train diagnostic information. The cab is pressure-sealed and air conditioned.

The ICE was designed with a 250 kmh (155 mph) maximum speed. However, test runs and operations have shown its ability to run safely and efficiently at 280 mph (174 mph) on the new and upgraded lines. Drivers are authorized to regain lost time due to delays by increasing speed to 280 kmh (174 mph). The ICE/V, the ICE's predecessor, which was designed for speeds of 300 kmh (186 mph), attained a maximum speed of 406.9 mph (252.9 mph) in May 1988, with no special changes or precautions, on the new Hannover-Würzburg line. ICE trainsets on the new Cologne-Frankfurt/Wiesbaden line will likely attain speeds of 300 kmh.

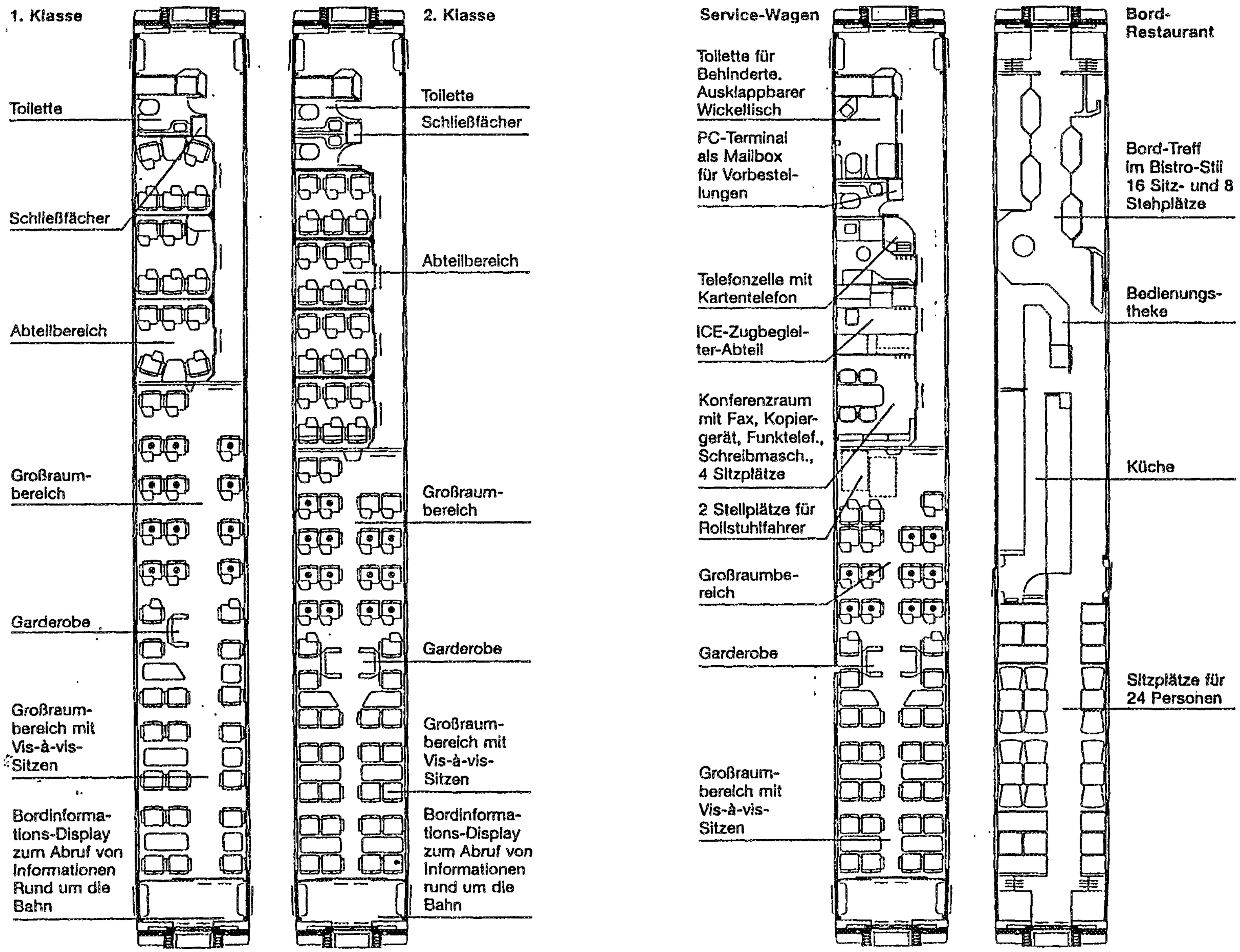
Trailer Cars[4]

In addition to the two power cars at each end, an ICE trainset normally has 11-14 intermediate trailer cars. Figure 9 displays the layout of an ICE trailer car and Table 3 summarizes their technical data. Currently, operating trainsets have 13 trailer cars: four first-class, seven second, and intervening dining and service cars. This gives each trainset a maximum capacity of 693 passengers, rising to 759 if another second-class car is added. In addition, a limited number of passengers may be accommodated in the restaurant car.

Table 3
ICE Trailer Car Specifications

Model number:	801-804
Height:	3.84 m standard, 4.295 m restaurant car
Width:	3.02 m
Length:	26.4 m
Weight:	53 tons (static)
Wheel radius:	0.92 m (new) — 0.87 m (used)
Axle spacing:	2.5 m
Brakes:	4 ventilated discs/axle, electropneumatic
Seating:	48/first-class car
	66/second-class car
	39/service car
Trailers/trainset:	11-14

Figure 9. Trailer Car Layout.



The ICE has two independent bogies per trailer, with pressure resistant gangways between trailers. This results in an additional 10 percent of space per trailer in comparison to the TGV, which uses a single bogie to connect trailer cars, resulting in the formation of a single articulated unit over the length of the train. The overall impression created by the ICE trailer cars is one of spaciousness and comfort. The trailer cars are 0.2 m wider than the standard DB car width to allow for extra seating room and gangway width.

Except for the restaurant and service cars, each trailer has three seating arrangements in the main compartment: single row facing one direction, single row facing each other, and double row facing each other. In addition, each car has compartments at one end, three in first class which seat five persons each, and four in second class which seat six persons each. The seats are airline style, with arm rest controls and the ability to recline. Each trailer has one or two bathrooms, a number of luggage lockers, and a wardrobe. The toilets are chemical-based and do not dump on the tracks, requiring them to be serviced regularly. Automatic sliding glass doors are at each end of a trailer car, providing access to the next car by way of a pressure-sealed gangway.

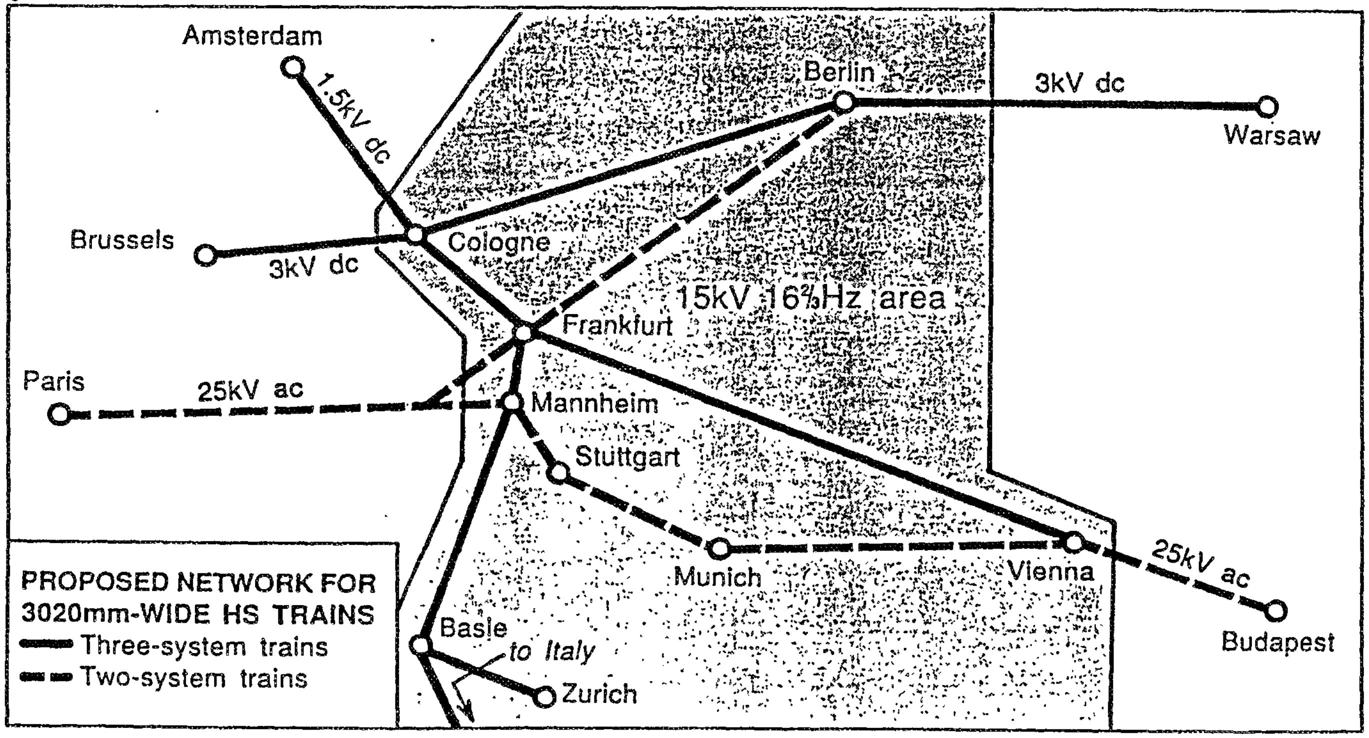
Amenities on board are numerous, including a conference room equipped with a copier, electric typewriter, fax machine, and international telephone. Each car is equipped with a wall-mounted computer passenger information system, which not only provides information about the route, but also allows passengers to book tickets and hotels. Throughout the train there are a number of card/coin-operated telephones and a cordless telephone. Headphones may be hired to listen to any of three radio stations or three on-board programs. The end trailers each have seating sections with flat video screens integrated into the seatbacks, allowing passengers to watch television or video programs.

Smokers and non-smokers have separate cars in the train. First-class passengers may enjoy dining and beverage service at their seats. The restaurant car is an extra 0.455 m in height and has skylights, which makes it very roomy and well-lit. There are 12 fixed and 12 loose seats in the non-smoking, waiter-service dining area, separated from a self-service bistro-bar by the kitchen.

ICE Multi-System[5]

The InterCity Express Multi-system (ICE-M) is the next generation of ICE trainsets. The key differences between it and the ICE is that the ICE-M will be less powerful, lighter, and shorter. It will be designed to operate on multiple voltage and signalling systems, enabling operations throughout Europe (see Figure 10). In addition, trainsets will normally have two power cars and six trailers, with the ability to combine trainsets for heavily travelled sections.

Figure 10. Track Voltage Systems in Europe.



MULTI-SYSTEM trains are needed to run outside Germany, Austria, and Switzerland.

Currently, there are plans for two types, the first of which is designed to operate on lines originating in Amsterdam-Cologne and beyond. This requires utilization of two voltage systems. The second is designed for the Paris-Brussels-Cologne-Frankfurt/Amsterdam (PBKF/A) line and beyond, requiring the ability to run on four systems– a reduction in weight to 17 tons per axle– and a smaller width. Less than a year ago, the DB was berating SNCF for its low allowable axle weight of 17 tons and small width of 2.888 m. It now appears to be compromising to ensure its ability to compete with the TGV in France and Belgium.

Table 4 summarizes the technical data for the first two ICE-M trainsets, (a) the Amsterdam-Cologneplus line, and (b) the PBKF/A plus line (see also Figures 11 and 12). Weight would have to be cut down for both systems in order to provide room for the extra power equipment. This may involve the use of carbon composite bogies, axleless independent-wheel bogies, air-sprung bogies, lighter power supply equipment, lighter interior coach components, and reduction of the power car's length. Maximum speeds would vary between 300-350 kmh (186-217 mph), depending on what track standards had been used to make the line. Trainsets capable of 400 kmh operations are under experimental development. The ruling grade is expected to rise from 3 percent to 4 percent.

Table 4
ICE-M Trainset Specifications

Formation:	2 power cars, 6 trailers
Gauge:	1.435 m
Voltage:	(a) 15 kV ac, 1.5 kV dc
	(b) 15 kV ac, 25 kV ac, 1.5 kV dc, 3 kV dc
Rated output:	(a) 6 mW (4 mW+2 mW), 2.5 mW dc
	(b) 7.2 mW (3.6 mW+3.6 mW), 2.5 mW dc
Trainset length:	200 m
Tractive effort:	166 kN
Height:	3.84/4.295 m
Width:	(a) 3.2 m
	(b) 2.888 m
Weight:	(a) 19 tons/axle
	(b) 17 tons/axle
Length:	19.16 – 21.4 m power car
Seating:	(a) 382 (95 first, 287 second)
	(b) 370 (112 first, 258 second)
Max. speed:	300 (350) kmh ac
	220 kmh dc
Ruling grade:	4%

(a) Amsterdam-Cologne line
(b) PBKF/A line

Figure 11. ICE-M Power Car Layout.

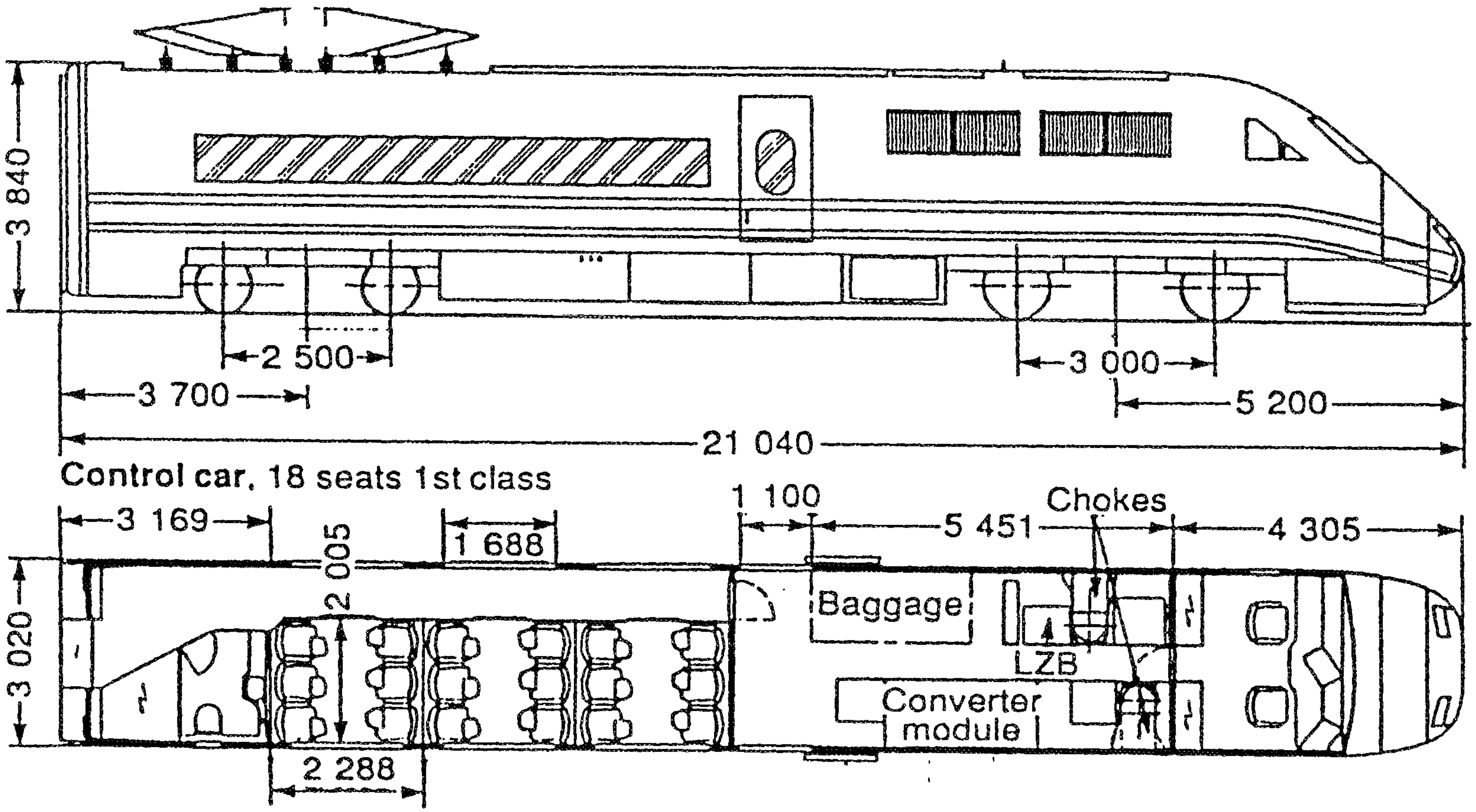
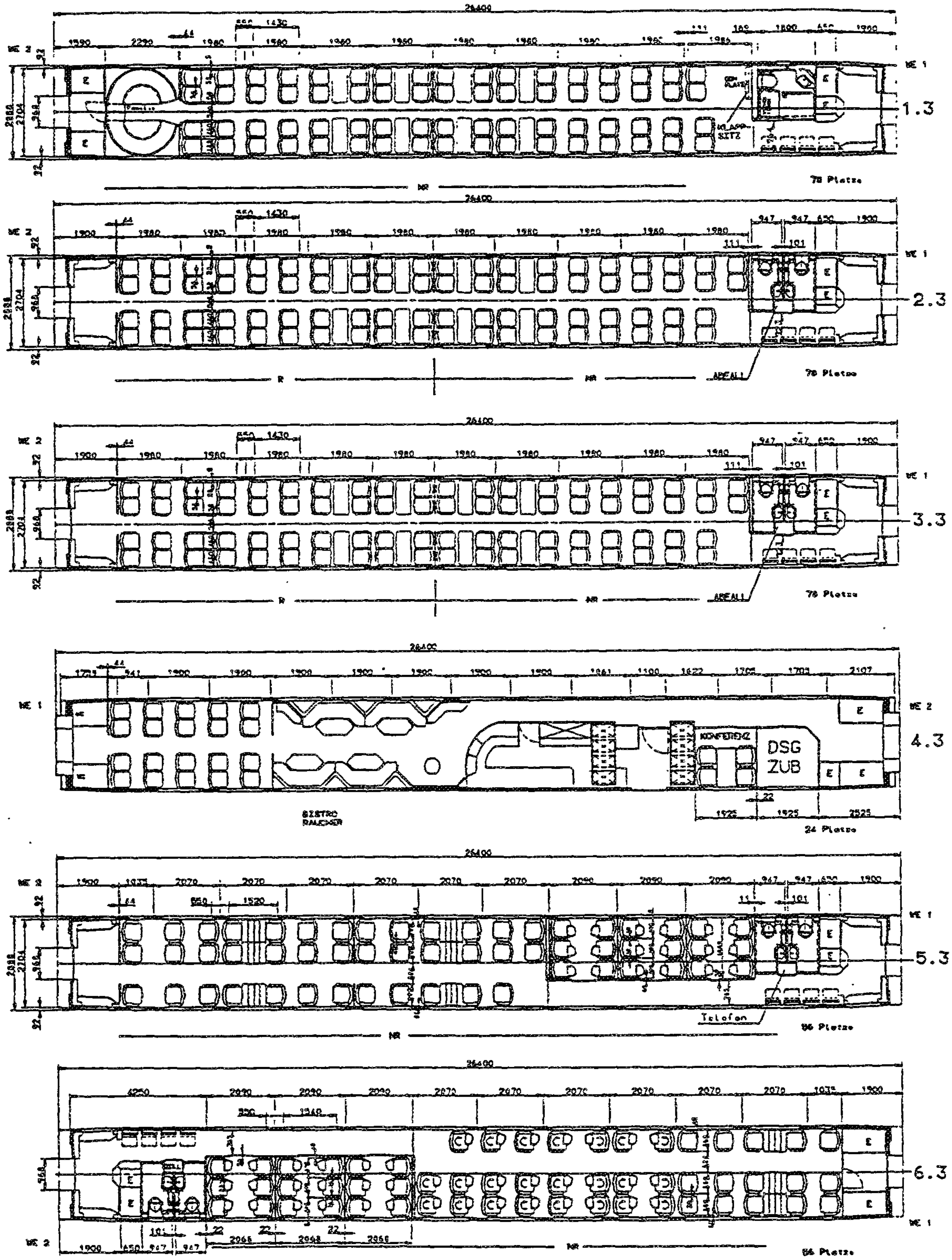


Figure 12. ICE-M Trailer Car Layout



2 KLASSE	258 PL	70%
1 KLASSE	112 PL	30%
GESAMT	370 PL	100%
ZUSATZLICH	20 NOTSITZE	

For the Amsterdam-Cologne run, the train will have six trailers, with three second-class cars, a service car with some seats and special facilities, a restaurant and bistro car, a first-class car, and three first-class compartments and a baggage compartment in one of the power cars. In Cologne, the train might be combined with another ICE-M trainset, forming a trainset with 2 end power cars, 2 intermediate power cars, and 12 trailers. They could later be split to continue on to separate destinations, such as Basel and Budapest.

The Paris-Brussels-Cologne-Frankfurt/Amsterdam trainset will have three second-class cars, one combination car with 32 second-class seats and a small bistro, and two first-class cars. It would be capable of coupling with other trainsets, as well as performing operations on multiple lines, including Berlin-Warsaw. If the new Channel link is built to UIC standards, ICE-M trainsets will be capable of travelling to London.

Relative to the TGV, its main competitor over these routes, the ICE will offer a higher level of comfort and service. The ICE will offer a full-service restaurant in addition to a self-serve bistro. On longer runs, it will also have couchette compartments. Both of these are unlikely on the TGV (Liebs, 1991).

The first ICE-M trainsets should be delivered by 1993/1994, enabling a fleet of seven trains to serve the Amsterdam-Cologne route by 1996, with an estimated total of 18 trainsets needed by 1998 when the Cologne-Frankfurt am Main line opens.

Freight

Preliminary considerations are underway for a version of the ICE for freight operations (ICE-G). Questions include whether to load freight on pallets or in containers. Design of the trailers, particularly the doors, is highly dependent on answering this question ("ICE-M...," May 1991: 24).

With the commencement of ICE operations, DB introduced a new cargo service, InterCargoExpress, which routinely operates at 160 kmh (100 mph) on the new and upgraded lines. InterCargoExpress provides overnight freight delivery to points between Hamburg and Munich, and Bremen and Stuttgart. Trials with the trains providing this service set a world speed record for freight trains when it reached 213 kmh (132 mph) during spring of 1991 ("DB...," May 1991: 12).

Reliability and Maintenance

The ICE was designed to very high standards of quality and reliability. Trainsets are expected to expected to travel 480,000 km (298,080 mi) annually and to be in operation up to 20 hours a day, approximately 60 percent more than conventional trainsets ("State...," January 1991: 27). This leaves little margin for maintenance problems or unreliability.

As previously noted, most maintenance and repair of trainsets is conducted at the ICE workshop at Eidelstedt in Hamburg, with some work also possible at Munich and Frankfurt-am-Main. On-board diagnostic systems monitor operations continuously and store any problems which arise during a run. On the 950 km run from Munich to Hamburg, this information is transmitted via radio to the maintenance facility from 200 km (124 mi) away in Hannover. This allows for scheduling of maintenance and repair operations within the 60-minute time allotted per trainset. There is only 1 hour and 49 minutes between the arrival of a trainset in Altona Hamburg and its departure. Two reserve trainsets are kept at Eidelstedt in case of severe problems or delays (ibid.).

The ICE's repair schedule is based on the kilometers travelled and is multi-layered. The shortest distance is 2,500 km (1,550 mi) or less, equivalent to a roundtrip Hamburg-Munich trip, and requiring the following procedures: checking all on-board diagnostics; visual check of brakes, bogies, shocks, wheel and axle sets, brakes, automatic couplers, motor suspension system, and oil coolant system; examination of pantographs; basic cleaning of passenger compartments; chemical toilet flush; restocking of restaurant facilities; and cleaning of outside surfaces. This procedure should take approximately one hour (Solf, 1987: 476).

A thorough interior cleaning is done every 30,000 km (18,600 mi). Every 60,000 km (37,200 mi), a number of major maintenance procedures are conducted: brake tuning and repair, wheel profile measurement and smoothing, air conditioning and kitchen facilities maintenance, battery and electrical system maintenance, passenger seat repair, and maintenance of passenger information system. These procedures are expected to require approximately eight hours and 120-150 workers to complete (ibid.).

Every 240,000 km (150,000 mi), the following procedures are conducted: ultrasonic checks of axles and frames; maintenance of trainset radios, electronic and fiber-optic systems; greasing of bogies, axles, shocks, and wheels; water-pipe decalcification; maintenance of air-pressure seals in the air conditioning systems, doors, and gangways; and steam cleaning of passenger compartments. This is expected to require 120-150 workers approximately eight hours to complete and an additional eight hours to dry (ibid.).

After 1.2 million km (745,000 mi), a number of major procedures are necessary: replacement of trailer bogies, overhaul of powered bogies, and replacement of wheels. In addition, new paint is applied every other 1.2 million km. This entire procedure is expected to require 13 working days (ibid.).

Replacement of all ICE components is possible in the Eidelstedt ICE workshop, including complete motor or bogie replacements, with the latter made in an hour or less (ibid.: 476-477).

Since the ICE has been operating for less than six months, reliability and maintenance information is not available. When operations began, complaints were made about the air conditioning system, doors which wouldn't seal, chemical toilets that didn't flush, and bumpy suspension systems. Such occurrences are common, however, until a system has been bedded-in.

4. IMPACTS

Environmental awareness and concern is very high in Germany and impact studies are an obligatory part of the planning process, forcing the Federal Railways to minimize impacts from construction and operations. Despite such efforts, resistance to the new lines and upgrading the old lines was severe and resulted in considerable delays. Such problems have forced the Federal Railways to further minimize their impacts and to create an education campaign about the benefits of the ICE and the environmentally sensitive efforts put into its construction.

Land

Impacts on the land are both human and physical in nature. Human impacts, such as the splitting of land holdings, are minimized by a program to compensate owners and consolidate holdings (Deutsche Bundesbahn, *Moderne...*: 18). The liberal use of tunnels on the new lines is not just to improve alignment, but also to avoid settlements and environmentally sensitive areas. Bridges serve a similar function by limiting the impact to the base of the structure. Embankments and cuttings have a more severe impact, although up to two-thirds of their area can be replanted, making them available to plant and animal life. If this was accomplished, only the 13.7 meter-wide track (45 ft) would be unavailable for reuse (Ellwanger, 1989/1990: 40).

Land use of the new lines is approximately one-third that of a modern highway in Germany: 3.0 hectares/km on the Hannover-Würzburg section, and 3.6 hectares/km on the Mannheim-Stuttgart section (ibid.). Construction of the new lines required 38.4 sqkm (14.8 sqmi), of which only 13.3 sqkm (5.1 sqmi) were retained for permanent use by the tracks, including embankments, cuttings, and sidings (Deutsche Bundesbahn, June 1991: 15). Along the length of the new and upgraded lines, the area's natural vegetation—be it forest, wetlands, or fields— and geography—be it hilly, flat, stream, or pond— has been incorporated to minimize the impact.

The construction phase is by far the most disturbing in terms of area and frequency of activity. The need for trucks was minimized through the use of pipelines and conveyor belts which transferred water and earth from local sources to the construction site and removed them when necessary. Fill was stored off-site for reuse later as embankments. Where reuse was not possible, fill was placed in dumps incorporated into the local geography and vegetation. Above- and underground streams were protected to insure that quantity and quality were retained after construction. Where disruption of water systems was anticipated during construction, replacement sources were found (Schrewe, 1989: 5-8).

Energy

It is largely accepted that rail uses less energy per passenger km travelled than the automobile, bus, or aircraft. Unfortunately, most of the evidence regarding energy use by the ICE is mainly anecdotal in nature, although some evidence is available.

In 1985, rail passenger transport in Germany was estimated at requiring 0.6 PJ per 1,000 million passenger km (1 PJ = 10-15 Joules). The equivalent figure for road passenger transport was 2.1 PJ. On the new Mannheim-Stuttgart line, specific energy consumption in 1995 of long-distance passenger rail transport is estimated to drop to 0.3 PJ per 1,000 million passenger km at a maximum speed of 250 kmh (Ellwanger, 1989/1990: 40).

Primary energy use includes the cost of conversion from a raw to usable energy form; for example, coal to electricity, or crude oil to gasoline. For purposes of comparison, an automobile with 4 passengers would use 279 Wh/Pkm at 115 kmh and an Airbus with 134 passengers would use 523 Wh/Pkm over an unspecified distance. The data is based on tests conducted by TÜV Rheinland, a company which tests the safety and performance of transport vehicles for the German government, such as the ICE and Transrapid Maglev (ibid.: 32). The following figures are for primary energy use in Watt hours/passenger km:

kmh	Wh/pkm
200	103
250	142
300	184

Secondary energy use is after energy has been converted from its original form, for example from coal to electricity, and does not include the energy loss due to conversion. These figures are for an ICE trainset with two motor cars and eight trailer cars with 402 seats, over a flat 600 km route with four intermediate stops spaced 120 km apart. These figures were developed by the institute responsible for information regarding the Transrapid Maglev, with the assistance of the Deutsche Bundesbahn and Thyssen Henschel (Versuchs- und Planungsgesellschaft für Magnetbahnsysteme, February 1991: 31). The following data is for secondary energy use in Watt hours/passenger km:

kmh	Wh/pkm
200	41
250	57
300	74

Pollution

Pollution from the ICE takes a number of forms: noise, particulates, electromagnetic emissions, water, and visual. The most noticable of these is noise. A conventional IC train generates 85 dB(A) at 160 kmh ("InterCity...," June 1990: 38). The following figures are for the ICE-Experimental (ICE-V) at a distance of 25 m:

kmh	dB(A)
160	79
200	82
250	85
300	89
400	102

The ICE generates essentially no on-site emissions, although one could dispute this with regard to oil and other chemicals that are lost from the underbody. Note that bathroom wastes and chemicals are not deposited on the track. However, production of electricity for use by the ICE does generate particulates, mainly through the burning of coal. The following figures are for milligrams/passenger km:

	mg/pkm				
kmh	CO	NOX	SO2	CH	CO2
200	2.6	10.7	8.9	0.25	14,000
300	4.6	19.2	15.9	0.44	25,000

This data is based on German emissions-control equipment, and the energy use figures are from the secondary energy use section above (Versuchs- und Planungsgesellschaft für Magnetbahnsysteme, February 1991: 33).

No specific mention of electromagenetic interference is made in the literature examined. Considering the state of the technology in Germany, this is perhaps not surprising. The pH value of ground and canal water has risen due to tunnel construction along the new lines. No specific causes or values are noted, but it is considered a problem (Schrewe, April 1989: 8). Visual pollution caused by the new lines is in many ways lessened by the perviously mentioned actions, such as tunnelling, slim construction bridges, contouring, and revegetation.

Safety

Given that the ICE only recently entered operation, it is difficult to judge its safety. However, it has to havd passed a thorough safety examination by the TÜV Rheinland, an institute hired by the German government to conduct safety checks on transport equipment, before being allowed to operate. The Deutsche Bundesbahn would also not allow the system to operate if it did not consider it safe. Mention has also already been made, however, of the electronic signalling system used over the ICE network.

Little mention of at-grade crossings is made in the literature, other than that they are removed in cooperation between Deutsche Bundesbahn and the federal, state, county, and local municipal governments. Removal is not considered mandatory, but is desired for operations on high speed lines (Deutsche Bundesbahn, *Moderne...*: 16). It is assumed that all at-grade crossing are removed on high speed lines.

In 1985, the German casualty rate for rail was 0.033 persons/million passenger km, as opposed to 0.804 persons/million passenger km for road (Ellwanger, 1988/1989: 39).

5. SERVICE

Provision of the necessary infrastructure and rolling stock were precursors to the goal of providing German high speed rail service. The ICE is designed to build on the strengths of this rail service: speed, comfort, reliability, and price. These strengths are used to capture potential high speed rail customers, the majority of which are business and wealthy travellers. These customers are very time-sensitive, requiring short journey times and a high degree of product availability, making it economically sensible to provide service only on routes with very high potential demand.

Marketing

- The marketing objectives of the DB is to improve the attractiveness of the railways by differentiating its products based on target groups and their needs, and to disseminate information regarding those products. According to P. Schnell, the Director of DB Passenger Marketing, there are three types of rail passenger traffic: high speed, long distance, and local. High speed rail traffic may combine elements of the other two, thereby increasing market share and making it the highest market segment (Schnell, February 1989: 47-48). High speed rail's main competitors are auto and air traffic, leading to the marketing motto: "Half as fast as the airplane, twice as fast as the car."

The ICE is designed to be distinct from other forms of rail and non-rail traffic, building on its advantages to provide services which they cannot. It is easily distinguishable externally by its sleek form, painted white with a red stripe, and internally by the previously described amenities. Its level of comfort is much higher than for conventional trains and is the highest among new high speed rail systems. Extensive marketing studies have shown this to be considered highly desirable by Germans and strongly affecting the choice not to drive or fly. This is understandable given the high quality of the air and road networks in Germany. Even if both are overburdened, the comfort of flying with Lufthansa or driving a Mercedes-Benz forces high speed rail service to provide an equivalent level of comfort. The ICE's frequency, speed, connection with other modes, and price also serve to distinguish it from other services within Germany (Liebs, 1990: 1037).

The ICE is also well integrated with other transportation systems in order to provide a seamless transportation network. Schedules are coordinated with EC and IC trains to provide cross-platform transfers, and trains will wait if the ICE is late. Since the ICE stops only at major stations, integration with regional and local transportation systems, such as InterRegio, S-Bahn and U-Bahn, is guaranteed.

Scheduling

The ICE operates between 4:53 am and 12:24 am daily (see Figures 13 and 14). Twenty trainsets leave the Hamburg Hauptbahnhof for Munich daily, one per hour from 5:07 am to 6:03 pm, and covering the 950 km (590 mi) route between the two end stations in 7 hours and 13 minutes. Twenty trainsets run daily between Munich and Hamburg-Hauptbahnhof, one per hour between 5:41 am and 8:41 pm, with the same trip time.

The reduction in trip times from 1990 to 1991 is considerable (see Figure 15). The trip between Hamburg and Munich will be reduced by two hours, a time savings of 20 percent. The

Figure 13. ICE Schedule: Hamburg to Munich.

Zug	Zugname	Tage	Hamburg-Altona Ab	Hamburg-Dammtor Ab	Hamburg Hbf. An	Hamburg Hbf. Ab	Hannover IC-Anschluss An	Hannover IC-Anschluss Ab	Göttingen An	Göttingen Ab	Kassel-Wilhelmshöhe An	Kassel-Wilhelmshöhe Ab	Fulda An	Fulda Ab	Frankfurt IC-Anschluss An	Frankfurt IC-Anschluss Ab	Mannheim IC-Anschluss An	Mannheim IC-Anschluss Ab	Stuttgart An	Stuttgart Ab	Ulm An	Ulm Ab	Augsburg An	Augsburg Ab	München An	Bemerkungen
ICE 891	Friedrich List	123456–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8 25	8 28	7.08	7.12	8 06	8 08	8.46	8 50	9 20	nicht 25.12.–1.1., 18.–20 4.; bis Stuttgart nur ①–⑤ ab 30 9., fährt Heidelberg ab 6.07, nicht 24 12.–1.1., 17.–20 4.
ICE 893	Prinzregent	12345––														6 14	6 54	6 57	7.38	7 42					9 45	nicht 24.12.–1.1., 17.–20.4
ICE 895	Rheingau	1234567	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					7 25	7 28	8 08	8 12	9 06	9 06	9 48	9 50	10 20	ab 30 9., fährt Wiesbaden ab 6 34, Mainz ab 6 45, Worms ab 7.11, nur ①–④
ICE 897	Herkules	123456–										6 18	6 46	6 47	7 42	7 46	8 25	8 28	9 08	9 12	10 06	10 08	10 46	10 50	11 20	nicht 25.12.–1.1., 18.–20 4., ab Kassel Hbf 6 09
ICE 591	Kommodore	1234567	4.53	5.00	5 03	5 07	6 18	6 20	6.52	6.54	7.14	7.16	7.46	7.47	8 42	8 48	9 25	9 28	10.08	10.12	11.06	11.08	11 46	11.50	12 20	bis Frankfurt nicht ⑦, nicht 25.12.–1.1., 18.–20 4.
ICE 593	Munchner Kindl	1234567	5 53	6 00	6 03	6 07	7.18	7 20	7.52	7.54	8 14	8 16	8 46	8 47	9 42	9 46	10 25	10 28	11 08	11.12	12 06	12 08	12 46	12 50	13 20	
ICE 595	Hohenstaufen	123456–	6 53	7 00	7.03	7 07	8 18	8 20	8,52	8,54	9.14	9.16	9 46	9.47	10.42	10 48	11 25	11 28	12.08	12.12	13.06	13 08	13 46	13 50	14 20	nicht 25.12.–1.1., 18.–20 4
ICE 597	Lessing	1234567	7 53	8 00	8 03	8 07	9 18	9 20	9 52	9 54	10 14	10 16	10 46	10 47	11 42	11 46	12 25	12 28	13 08	13.12	14 06	14 08	14 46	14 50	15 20	
ICE 599	Kurpfalz	1234567	8 53	9.00	9 03	9 07	10.18	10 20	10.52	10.54	11.14	11.16	11.46	11 47	12.42	12.46	13 25	13 28	14 08	14.12	15.06	15 08	15 46	15.50	16.20	[illegible]
ICE 691	Hölderlin	1234567	9 53	10 00	10 03	10 07	11.18	11 20	11.52	11.54	12.14	12.16	12 46	12 47	13 42	13 46	14 25	14 28	15 08	15.12	16 06	16 08	16 46	16.50	17.20	
ICE 693	Nymphenburg	1234567	10 53	11,00	11,03	11.07	12.18	12.20	12 52	12.54	13.14	13.16	13 46	13,47	14.42	14,46	15.25	15.28	16 08	16.12	17.06	17.08	17,46	17.50	18 20	[illegible]
ICE 695	Herrenhausen	1234567	11 53	12 00	12 03	12 07	13 18	13 20	13 52	13.54	14 14	14 16	14 46	14 47	15 42	15.46	16 25	16 28	17 08	17.12	18 06	18 08	18 46	18 50	19 20	
ICE 697	Diamant	1234567	12.53	13 00	13 03	13.07	14.18	14.20	14 52	14.54	15.14	15.16	15.46	15 47	16.42	16 46	17.25	17.28	18.08	18.12	19.06	19 08	19.46	19.50	20 20	[illegible]
ICE 899	Kondor	——5——	13 29	13 36	13 39	13 42	14 59	15 07	15 40	15 42	16 02	16 04	16.34	16 35	17.30	17 35	18 17	18 20	19 13							auch 16., 30 4., nicht 17 4., 1 5., fährt Hamburg-Harburg ab 13 52, Lüneburg ab 14 08
ICE 699	Franz Kruckenberg	12345–7	13 53	14.00	14.03	14 07	15.18	15 20	15.52	15.54	16.14	16.16	16 46	16 47	17.42	17.46	18 25	18 28	19 00	19.12	20 06	20 08	20,46	20.50	21 20	nicht 24.–31.12., 17.–19 4.
ICE 791	Gambrinus	1234567	14 53	15 00	15 03	15 07	16 18	16 20	16 52	16.54	17.14	17 16	17.46	17 47	18 42	18 46	19 25	19 28	20 08	20 12	21 06	21 08	21 46	21.50	22 20	
ICE 793	Seewind	1234567	15 53	16 00	16 03	16 07	17.18	17 20	17 52	17.54	18.14	18 16	18.46	18 47.	19 42	19 46	20 25	20 28	21.08	21.12	22 06	22 08	22.46	22.50	23 20	ab Stuttgart nur ⑦, auch 1.1., 20.4., nicht 29 12., 19 4.
ICE 795	Senator	12345–7	16 53	17 00	17.03	17 07	18 18	18 20	18 52	18 54	19 14	19 16	19 46	19 47	20 42	20 46	21.25	21 28	22 08							nicht 24.–31.12., 17.–19 4.
ICE 797	Saphir	1234567	17.53	18.00	18 03	18 07	19.18	19 20	19 52	19.54	20.14	20.16	20 46	20.47	21.42	21.46	22.25	22.28	23 09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ICE 799	Brahms	1234567	18 53	19 00	19 03	19 07	20 18	20 20	20 52	20 54	21.14	21 16	21 46	21 47	22 42											an Mainz 23.10, an Wiesbaden 23 22 außer ⑥ ab 29 9., nicht 24.-31.-12., 17.-19 4.
ICE 899	Lüneburger Heide	12345–7	19 53	20.00	20 03	20 07	21.18	21 20	21 52	21 54	22.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	nicht 24.–31.12., 17.–20 4., an Kassel Hbf 22 33

Figure 14. ICE Schedule: Munich to Hamburg.

			München	Augsburg		Ulm		Stuttgart		Mannheim IC-Anschluss		Frankfurt IC-Anschluss		Fulda		Kassel - Wilhelmshöhe		Göttingen		Hannover IC-Anschluss		Hamburg Hbf.		Hamburg - Dammtor	Hamburg - Altona	
Zug	Zugname	Tage	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	Ab	An	An	Bemerkungen
ICE 898	Lüneburger Heide	123456–															6.42	7.03	7.05	7.38	7.40	8.51	8.54	8.57	9.04	nicht 25.12.–1.1., 18.–20.4., Kassel Hbf ab 6.25
ICE 798	Brahms [illegible]	123456–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.17	7.11	7.12	7.42	7.44	8.03	8.05	8.38	8.40	9.51	9.54	9.57	10.04	nicht 25.12.–1.1., 18.–20.4.; fährt Wiesbaden ab 5.37, Mainz ab 5.48; [illegible]
ICE 796	Saphir	1234567							5.53	6.31	6.34	7.13	7.17	8.11	8.12	8.42	8.44	9.03	9.05	9.38	9.40	10.51	10.54	10.57	11.04	bis Frankfurt ①–⑤ und nicht 24.12.–1.1., 17.–20.4
ICE 794	Senator [illegible]	1234567	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.53	7.31	7.34	8.13	8.17	9.11	9.12	9.42	9.44	10.03	10.05	10.38	10.40	11.51	11.54	11.57	12.04	[illegible]
ICE 792	Seewind	1234567	5.41	6.08	6.10	6.51	6.53	7.49	7.53	8.31	8.34	9.13	9.17	10.11	10.12	10.42	10.44	11.03	11.05	11.38	11.40	12.51	12.54	12.57	13.04	bis Stuttgart ①–⑤ und nicht 24.12.–1.1., 17.–20.4
ICE 790	Gambrinus [illegible]	1234567	6.41	7.08	7.10	7.51	7.53	8.49	8.53	9.31	9.34	10.13	10.17	11.11	11.12	11.42	11.44	12.03	12.05	12.38	12.40	13.51	13.54	13.57	14.04	[illegible]
ICE 698	Franz Kruckenberg	123456–	7.41	8.08	8.10	8.51	8.53	9.49	9.53	10.31	10.34	11.13	11.17	12.11	12.12	12.42	12.44	13.03	13.05	13.38	13.40	14.51	14.54	14.57	15.04	nicht 25.12.–1.1., 18.–20.4
ICE 696	Diamant [illegible]	1234567	8.41	9.08	9.10	9.51	9.53	10.49	10.53	11.31	11.34	12.13	12.17	13.11	13.12	13.42	13.44	14.03	14.05	14.38	14.40	15.51	15.54	15.57	16.04	[illegible]
ICE 694	Herrenhausen	1234567	9.41	10.08	10.10	10.51	10.53	11.49	11.53	12.31	12.34	13.13	13.17	14.11	14.12	14.42	14.44	15.03	15.05	15.38	15.40	16.51	16.54	16.57	17.04	
ICE 692	Nymphenburg [illegible]	1234567	10.41	11.08	11.10	11.51	11.53	12.49	12.53	13.31	13.34	14.13	14.17	15.11	15.12	15.42	15.44	16.03	16.05	16.38	16.40	17.51	17.54	17.57	18.04	[illegible]
ICE 690	Hölderlin	1234567	11.41	12.08	12.10	12.51	12.53	13.49	13.53	14.31	14.34	15.13	15.17	16.11	16.12	16.42	16.44	17.03	17.05	17.38	17.40	18.51	18.54	18.57	19.04	
ICE 598	Kurpfalz [illegible]	1234567	12.41	13.08	13.10	13.51	13.53	14.49	14.53	15.31	15.34	16.13	16.17	17.11	17.12	17.42	17.44	18.03	18.05	18.38	18.40	19.51	19.54	19.57	20.04	[illegible]
ICE 596	Lessing	1234567	13.41	14.08	14.10	14.51	14.53	15.49	15.53	16.31	16.34	17.13	17.17	18.11	18.12	18.42	18.44	19.03	19.05	19.38	19.40	20.51	20.54	20.57	21.04	
ICE 594	Hohenstaufen [illegible]	1234567	14.41	15.08	15.10	15.51	15.53	16.49	16.53	17.31	17.34	18.13	18.17	19.11	19.12	19.42	19.44	20.03	20.05	20.38	20.40	21.51	21.54	21.57	22.04	[illegible]
ICE 592	Münchner Kindl	12345–7	15.41	16.08	16.10	16.51	16.53	17.49	17.53	18.31	18.34	19.13	19.17	20.11	20.12	20.42	20.44	21.03	21.05	21.38	21.40	22.51	22.54	22.57	23.04	nicht 24.–31.12., 17.–19.4
ICE 590	Kommodore [illegible]	1234567	16.41	17.08	17.10	17.51	17.53	18.49	18.53	19.31	19.34	20.13	20.17	21.11	21.12	21.42	21.44	22.03	22.05	22.38	22.40	23.51	23.54	23.57	0.04	[illegible]
ICE 896 ICE 996	Herkules	12345–7	17.41	18.08	18.10	18.51	18.53	19.49	19.53	20.31	20.34	21.13	21.17	22.11	22.12	22.42	22.44	23.03	23.05	23.38						nicht 24.–31.12., 17.–19.4; an ①–⑤ nur bis Kassel bis Hannover auch 1.1., 20.4.
ICE 894	Rheingau [illegible]	1234567	18.41	19.08	19.10	19.51	19.53	20.49	20.53	21.31	21.34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	fährt Worms an 21.48, Mainz an 22.14, Wiesbaden an 22.28 [illegible]
ICE 892	Prinzregent	12345–7	19.41	20.08	20.10	20.51	20.53	21.49																		nicht 24.–31.12., 17.–19.4
ICE 990	Main-Kurier [illegible]	12345–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.55	22.35	22.37	23.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ab 30.9., nicht 24.12.–1.1., 17.–20.4, [illegible]
ICE 890	Friedrich List	———7	20.41	21.08	21.10	21.51	21.53	22.49																		auch 1.1., 20.4; nicht 29.12., 19.4
ICE 992	Neckar-Kurier [illegible]	———7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.53	[illegible]	[illegible]	0.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ab 29.9., auch 1.1., 20.4., nicht 29.12., 19.4. fährt Heidelberg ab 23.36 [illegible]

Figure 15. ICE Trip Times 1990/1991.

Reisezeiten 1990/1991
(in Minuten)

1990

	Hamburg	Hannover	Göttingen	Kassel	Fulda	Frankfurt	Mannheim	Stuttgart	Augsburg	München
Hamburg		76	134	*	212	277	330	415	521	554
Hannover	71		56	*	134	199	252	337	443	476
Göttingen	105	32		*	78	141	194	279	385	418
Kassel	127	54	20		*	*	*	*	*	*
Fulda	159	86	52	30		63	116	201	307	340
Frankfurt	215	142	108	86	55		46	131	237	270
Mannheim	258	185	151	129	98	39		80	186	219
Stuttgart	301	228	194	172	141	82	40		100	133
Augsburg	401	328	294	272	241	182	140	96		31
München	433	360	326	304	273	214	172	128	30	

1991 (ab Mai)

*keine durchgehende IC-Verbindung

introduction of Hamburg-Munich services via Wurzburg in late 1991/early 1992 will further reduce this time. The trip between Hannover and Frankfurt will drop by nearly an hour, a savings of 30 percent. The trip time between Frankfurt and Munich will drop by nearly one hour, a savings of 21 percent. The trip time between Mannheim and Stuttgart will be reduced by half.

As can be seen from these figures, average speeds attained by the ICE are 120-160 kmh (75-99 mph). It should be remembered, however, that distances between stops are 100-150 km (60-95 mi) and population densities in Germany are very high, making it difficult to maintain high speeds.

Fares[6]

With the introduction of ICE services, German rail traffic fares are no longer based on a flat rate per km travelled. Instead, rates are now based on competing modes, class of travel, time of day, and day of week (see Figure 16). All tickets include a reservation, with an additional fee of DM 10 ($6.7) if the complete ticket is bought on-board the ICE. Reservations are strongly suggested, particularly on early morning and evening trains. Ticketing can be done in person at DB ticket counters in stations or by authorized travel agents, as well as by phone, with home computer bookings expected to come on-line in the near future.

One-way fares are DM 1.2-24 ($0.80-16.08) for second class and DM 2-40 ($1.34-26.80) more expensive for first class than for an InterCity (IC) train providing service on the same route (see Figure 17). Two-way fares are simply double the one-way fare. The largest difference is between points of high demand with few competitive alternatives, such as auto or air. Hannover-Frankfurt fares are DM 104 ($69.68) second class and DM 160 ($107.20) first class, averaging DM 0.31 and DM 0.47 per kilometer ($0.33 and $0.51 per mile). The total fares are DM 19 ($12.73) and DM 35 ($23.45) more expensive than IC fares over the same route. Frankfurt-Stuttgart fares are DM 66 ($44.22) second class and DM 98 ($65.66) first class, DM 0.35 and DM 0.53 per kilometer ($0.38 and $0.57 per mile). These fares represent a total increase of DM 14 ($9.38) and DM 23 ($15.41) over IC fares.

Fares for routes that are less competitive with the alternatives are considerably less. Hamburg-Munich fares are DM 200 ($134) second class and DM 300 ($201) first class, DM 0.24 and DM 0.32 per kilometer ($0.23 and $0.34). The total fares are only DM 4 ($2.68) and DM 9 ($6.03) above the same fares on the IC. Frankfurt-Munich fares are DM 104 ($69.68) second class and DM 156 ($104.52) first class, an average of DM 0.24 and DM 0.36 per kilometer ($0.26 and ($0.39). These are only DM 5 ($3.35) and DM 10 ($6.70) over IC fares.

Figure 16. ICE Fares.

ICE-Fahrpreise je Richtung (in DM).

von	nach	Hamburg	HH-Harburg	Lüneburg	Hannover	Göttingen	Kassel	Fulda	Frankfurt	Mainz	Wiesbaden	Worms	Mannheim	Heidelberg	Stuttgart	Ulm	Augsburg	München
Hamburg	1.Kl.	15	15	26	78	116	130	172	212	212	212	230	230	230	272	280	300	300
	2.Kl.	10	12	20	52	78	88	112	144	144	144	156	156	156	182	190	200	200
HH-Harburg	1.Kl.			20	72	110	124	166	206	206	206	224	224	224	266	274	300	300
	2.Kl.			16	48	74	84	108	140	140	140	152	152	152	178	186	200	200
Lüneburg	1.Kl.				54	98	112	154	194	194	194	212	212	212	254	262	300	300
	2.Kl.				38	66	76	100	132	132	132	144	144	144	170	178	200	200
Hannover	1.Kl.					56	76	116	160	166	166	178	178	178	226	234	260	280
	2.Kl.					38	50	76	104	108	108	118	118	118	150	156	176	190
Göttingen	1.Kl.						32	60	104	110	110	130	128	128	170	184	224	244
	2.Kl.						24	40	72	76	76	90	90	90	114	126	152	166
Kassel	1.Kl.						15	50	86	92	92	114	112	112	154	174	208	230
	2.Kl.						10	36	62	66	66	80	80	80	106	120	142	156
Fulda	1.Kl.								52	58	58	82	80	80	114	130	176	196
	2.Kl.								36	42	42	58	58	58	82	90	120	134
Frankfurt	1.Kl.									22	22	46	44	44	98	110	140	156
	2.Kl.									16	16	30	30	30	66	76	94	104
Mainz	1.Kl.										14	24	30	38	88	110	140	162
	2.Kl.										10	18	22	28	58	78	96	110
Wiesbaden	1.Kl.											26	36	40	92	114	142	164
	2.Kl.											20	26	30	62	80	98	112
Worms	1.Kl.												18	22	74	96	126	156
	2.Kl.												14	18	50	66	86	100
Mannheim	1.Kl.													14	66	90	116	150
	2.Kl.													12	44	60	78	94
Heidelberg	1.Kl.														72	96	122	156
	2.Kl.														48	64	82	98
Stuttgart	1.Kl.															42	70	94
	2.Kl.															30	50	64
Ulm	1.Kl.																38	60
	2.Kl.																28	42
Augsburg	1.Kl.																	34
	2.Kl.																	24

Bei Kauf des ICE-Fahrscheins im Zug 10,- DM Aufschlag.

Tarifstand: 01.03.1991

Figure 17. ICE Fare Surcharge Above IC Fares.

ICE-Aufpreise je Richtung (in DM).

von \ nach		Hamburg	HH-Harburg	Lüneburg	Hannover	Göttingen	Kassel	Fulda	Frankfurt	Mainz	Wiesbaden	Worms	Mannheim	Heidelberg	Stuttgart	Ulm	Augsburg	München
Hamburg	1.Kl.	4,8	3	2	12	14	7	23	27	15	14	9	17	17	26	5	9	9
	2.Kl.	1,2	2	2	6	8	4	11	19	11	10	7	12	12	16	5	4	4
HH-Harburg	1.Kl.			2	12	12	7	22	27	14	14	9	17	17	24	4	9	9
	2.Kl.			2	6	7	4	10	19	10	10	7	12	12	15	4	4	4
Lüneburg	1.Kl.				4	14	7	23	27	15	14	9	17	17	26	5	9	9
	2.Kl.				3	8	4	11	19	11	10	7	12	12	16	5	4	4
Hannover	1.Kl.					14	13	27	35	29	28	17	26	25	40	19	5	4
	2.Kl.					8	6	15	19	15	14	9	15	14	24	11	4	4
Göttingen	1.Kl.						4	9	15	9	8	5	11	11	20	5	5	4
	2.Kl.						3,6	4	11	7	6	5	10	10	12	5	4	4
Kassel	1.Kl.							6	5	11	6	5	4	10	8	14	4	4	5
	2.Kl.							2	4	10	7	6	5	10	9	11	5	4	4
Fulda	1.Kl.								11	5	4	5	11	9	10	4	5	4
	2.Kl.								7	5	4	5	10	9	11	4	4	4
Frankfurt	1.Kl.									4	1	4	10	7	23	6	14	10
	2.Kl.									2	0	0	5,4	3,4	14	5	8	5
Mainz	1.Kl.										2	3	2	1	11	3	5	6
	2.Kl.										0	1,8	1,6	1,4	6	5	4	4
Wiesbaden	1.Kl.											2	3	1	11	3	4	6
	2.Kl.											2	1,8	2	6	4	4	5
Worms	1.Kl.												3	1	15	8	7	18
	2.Kl.												2	1,8	9	4	5	6
Mannheim	1.Kl.													1	16	9	8	21
	2.Kl.													1,4	9	4	4	6
Heidelberg	1.Kl.														16	10	8	21
	2.Kl.														9	5	4	6
Stuttgart	1.Kl.															5	5	8
	2.Kl.															3,4	5	5
Ulm	1.Kl.																4	6
	2.Kl.																3,4	4
Augsburg	1.Kl.																	6
	2.Kl.																	3,6

Bei Nachlösen im Zug oder im Ausland 4,- DM (1. Klasse) und 3,- DM (2. Klasse) Aufschlag.

Tarifstand: 01.03.1991

Numerous special ticket packages aimed at reducing costs are offered, aimed at the non-business traveller. These are based primarily on distance travelled and flexibility. An ICE "Sparpreis" or "savings price" ticket is DM 220 second class and DM 330 first class, DM 30 and DM 45 more, respectively, than the equivalent ticket on the IC. This ticket is good for a round-trip at least 438 km one-way (876 km round-trip), with the restriction that the return trip cannot be made until the Saturday following the day on which the trip begins (Deutsche Bundesbahn, *Preise*, June 1991: 10).

An ICE "Super-Sparpreis" or "super savings price" ticket is DM 180 ($120.60) second class and DM 270 ($180.90) first class, DM 40 ($26.80) and DM 60 ($40.20) more expensive for the same ticket on the IC. This ticket is good for a round-trip at least 324 km (201 mi) one-way (648 km round-trip), with the restriction that the return trip cannot be made until the Saturday following the day on which the trip began, which may include the same day if the trip begins on a Saturday, but travel is not allowed on the next Friday or Sunday, nor on extremely heavy travel days, such as around Christmas and New Year's (ibid.: 11). Other special tickets good on the ICE include monthly and yearly tickets, group tickets, youth tickets, and senior citizen tickets. Each of these has its own particular set of restrictions and is more expensive than the equivalent ticket on the IC (ibid.).

Finally, if the ICE is more than 30 minutes late, the passenger is given a coupon worth the difference between the ICE fare and the equivalent fare on the IC, to be applied toward the next ICE ticket (Deutsche Bundesbahn, March 1991: 5).

Demand

Currently, German long-distance rail passenger traffic generates approximately 22 billion passenger km (13.7 billion passenger mi) annually, with InterCity and EuroCity services accounting for half of this figure. Long-distance rail-passenger traffic is expected to rise about 30 percent by the year 2000 due to the ICE. This is equivalent to 7 billion pkm (4.3 billion pmi) annually, with 3.2 billion pkm (1.99 billion pmi) generated by the Hannover-Würzburg and Mannheim-Stuttgart new lines, and 3.8 billion pkm (2.36 billion pmi) from the Karlsruhe-Basel new and upgraded lines. The Cologne-Frankfurt/Wiesbaden new lines are expected to generate an additional 3.6 billion pkm (2.24 billion pmi), an increase of 70 percent relative to current rail traffic on the route (Deutsche Bundesbahn, July 1990: 5; "InterCity Revolution," June 1990: 35-36).

Load factors previously averaged 43 percent on IC trains, and DB hopes that they will rise to 50 percent or more on the ICE. The increased demand is expected to come 5 percent from automobile traffic and 25-35 percent from air traffic ("InterCity Revolution," June 1990: 36).

In the first one hundred days of operation, ridership increased 20 percent along the ICE route, with an average train occupancy of 54 percent. Business travellers made up 35 percent of the passengers, as opposed to 26 percent on the IC. First-class passengers were 16 percent of the total, 70 percent of which were business travellers. Passengers travelled an average of 325 km (202 mi), 50 km (31 mi) further than when on the IC. The ICE received an overall grade from passengers of 1.8 with a maximum of 1 and a minimum of 4 (Deutsche Bundesbahn, "Bundesbahn...," 1991).

6. ECONOMICS[7]

The costs of the ICE infrastructure and rolling stock is such that a return on investment is not expected for years. However, preliminary results have been positive and long-term returns are expected to be high.

Costs

At the commencement of ICE operations in June 1991, total investment in the ICE network, including infrastructure and rolling stock, was approximately DM 20 ($13.4) billion. This figure is expected to rise to at least DM 34 billion by the completion of the 2000 km (1242 mi) network at end of the century (Deutsche Bundesbahn, "2,000...," March 1991: 6; "Heavy...," June 1990: 61).

The two new lines, Hannover-Würzburg and Mannheim-Stuttgart, cost approximately DM 16 billion alone, averaging out to DM 37.5 million per km ($40.5 million per mi) to construct. Environmental measures accounted for approximately 10 percent of this expense. Upgrading six sections for high speed service cost an additional DM 1.6 ($1.1) billion (ibid.). The new Cologne-Frankfurt/Wiesbaden line is estimated to cost DM 5.4-7.5 ($3.6-5.0) billion for the approximately 200 km (124 mi) route, averaging DM 27.0-37.5 million per km ($29.0-40.3 million per mile) to construct (Deutsche Bundesbahn, "Neubausstrecke...," March 1991: 8).

The new computer signalling system cost DM 126 ($84.4) million [1990] (Deutsche Bundesbahn, March 1990: 7). Construction of the new Kassel-Wilhelmshöhe station cost DM 300 ($201) million, out of which DM 80 ($53.6) million was for design changes during construction (Langer, July 1991: 290). Construction of the Eidelstedt workshop in Hamburg cost DM 300 ($201) million ("State...," January 1991: 27).

An ICE trainset with 2 power cars and 13 trailer cars costs DM 50 ($33.5) million, for an average cost of DM 70,000 ($46,900) per seat ("IC91...," May 1991; "Beyond...," May 1991: 299).

The first 60 trainsets are expected to cost DM 2.95 ($1.98) billion [1990] ("InterCity Revolution," June 1990: 35). No break-down on cost per power car or trailer has been formulated.

The ICE-M is expected to cost DM 8 ($5.36) million for a full power car and DM 5 ($3.35) million for a partial power car with a passenger seating compartment (ICE-M Starts...," May 1991: 24). Cost per seat is estimated at DM 110,000 ($73,700) ("Beyond...," May 1991: 301).

Revenues

Although it is still too early to estimate accurately the return on investment, preliminary results indicate that the ICE has gotten off to a good start in Germany. One hundred days after its introduction into regular service on June 2, 1991, the ICE had transported 2.5 million persons, generating DM 125 ($83.75) million, one half of which was from discount and special tickets (Deutsche Bundesbahn, "Bundesbahn...," 1991).

By the turn of the century, ICE operations are expected to generate DM 2 ($1.34) billion annually [1990] ("ICE-Höchstgeschwindkigkeit...," June 1990: 32). Construction of the new Hannover-Würzburg and Mannheim-Stuttgart lines is expected to result in a savings of DM 500 ($335) million annually, due to the generation of new traffic and the improvement of existing operations along the lines ("Heavy...," June 1990: 63).

7. SUMMARY

The ICE is one piece in a program to improve transportation in Germany. It has evolved through a series of parallel steps designed to improve the level of services offered by rail in Germany. As with all transportation systems, the success of the ICE is a function of its infrastructure, rolling stock, and level of service, including intergration with other transportation networks.

The first step towards the creation of a high speed rail network in Germany was the decision to invest in 2,000 km (1,242 mi) of tracks capable of handling passenger trainsets operating at speeds of 200-250 kmh (124-155 mph). In addition to carrying ICE trainsets for 20 hours of the day, these lines also carry freight traffic at night, except for an as yet to be constructed segment, which will be dedicated and designed for ICE operations up to 300 kmh (186 mph).

The next step was the design and construction of new rolling stock, using new technologies to allow safe and efficient operations at such high speeds. After significant work with experimental trainsets, new ICE power and trailer cars have recently entered commercial operations.

The level of service provided by the ICE is a function of the infrastructure and rolling stock, in addition to scheduling, pricing, and integration with other networks. In comparison to other high speed rail systems, the ICE's level of comfort is the highest, although travel time and frequency may lag behind.

The ICE is targeted toward travellers who value short travel time, high availability, high comfort levels, integration with other systems, and reasonable price. These travellers are typically business people and wealthy private persons.

Research into improving the ICE continues and will soon result in the ICE-M, with trainsets capable of operations at 300 kmh (186 mph) throughout Europe via a European high speed rail network. The ICE-M will also provide the high level of comfort and service found on the ICE currently operating in Germany. At least one new route segment, Cologne-Frankfurt/ Wiesbaden, will be designed for speeds of 350 kmh (217 mph) in anticipation of further speed gains based on research currently underway on the ICE-V and ICE-M.

Preliminary results indicate that the ICE is successful in the market it has chosen, although it is too early to compare its impact on air or automobile transportation along similar routes. The TGV is the ICE's strongest competitor, making it interesting to see if the large and ongoing investments made toward the ICE will result in as successful a system capable of operations in Germany and throughout Europe.

NOTES

[1]Unless otherwise noted, all monetary figures in this paper are in 1991 amounts: DM 1 = $0.67.

[2]The information for this section is from the following sources: "Beyond...," May 1991; "Inside...," May 1991; Hase, June 1990; "InterCity Express...," June 1990; "Many...," June 1990; Deutsche Bundesbahn, 1990; Kurz, 1989.

[3]Information for this section is from the following sources: "InterCity Express...," June 1990; AEG, ABB, Siemens; AEG, ABB, Krauss-Maffei, Krupp, Siemens, Thyssen; Deutsche Bundesbahn, "Moderne...."

[4]The technical data for this section is from the following sources: "Inside...," May 1991; Deutsche Bundesbahn, 1990; Deutsche Bundesbahn, November 1990; Kurz, 1989; Lankes, May 1989.

[5]This information is from the following sources: "Beyond...," May 1991; "ICE-M Starts...," May 1991; Kurz, June 1990; "Multi-...," June 1990.

[6]Unless otherwise noted, all fares are in 1991 amounts: DM 1 = $0.67.

[7]Unless otherwise noted, all costs and revenues are in 1991 amounts: DM 1 = $0.67.

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