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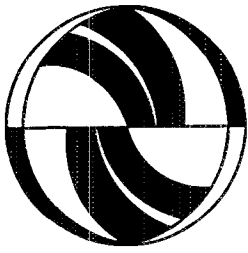
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British Rail's InterCity 125 and 225

Roger Barnett

Working Paper
UCTC No. 114

**The University of California
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British Rail's InterCity 125 and 225

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CALIFORNIA HIGH SPEED RAIL SERIES

Working Paper
June 1992

UCTC No. 114

The University of California Transportation Center
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BRITISH RAIL InterCity 125(HST) and InterCity 225

INTRODUCTION

The purpose of this report is to provide a technical review of the two high-speed rail systems developed by British Rail — the InterCity 125 and 225 — over the past 20 years, so that they can be compared with other systems for possible future use in the development of a high-speed passenger rail system in California. While the report will examine both systems, greater attention will be given to the newer IC-225 technology, which was introduced in 1990 and uses electric traction. The older IC-125 technology, dating from the mid-1970s in revenue service, merits study as the only example of a high-speed passenger train using diesel traction. These two technologies are of additional interest to the CalSpeed project because British Rail has built no dedicated lines for high-speed services. Other than the tilt trains introduced recently introduced in Sweden and Italy, the IC-125/225 trains are the only conventional high-speed services relying solely on the upgrading of existing tracks of a long-established rail network.

The report follows the format used in the other CalSpeed working papers which have surveyed other technologies:

1. General background to the development of the high-speed train sets.
2. Engineering characteristics; including motors, vehicles, tracks, and train control.
3. Performance features; including speed, grades/curves, passenger capacity, and reliability.
4. Environmental impact.
5. Revenues by train/mile, and by class of service provided.
6. Costs; including capital, operating, and maintenance.
7. Present status of system and future developments.

The following abbreviations are used in the report (and I have shortened the IC-125 or IC-225 to simply 125 or 225 trains, respectively):

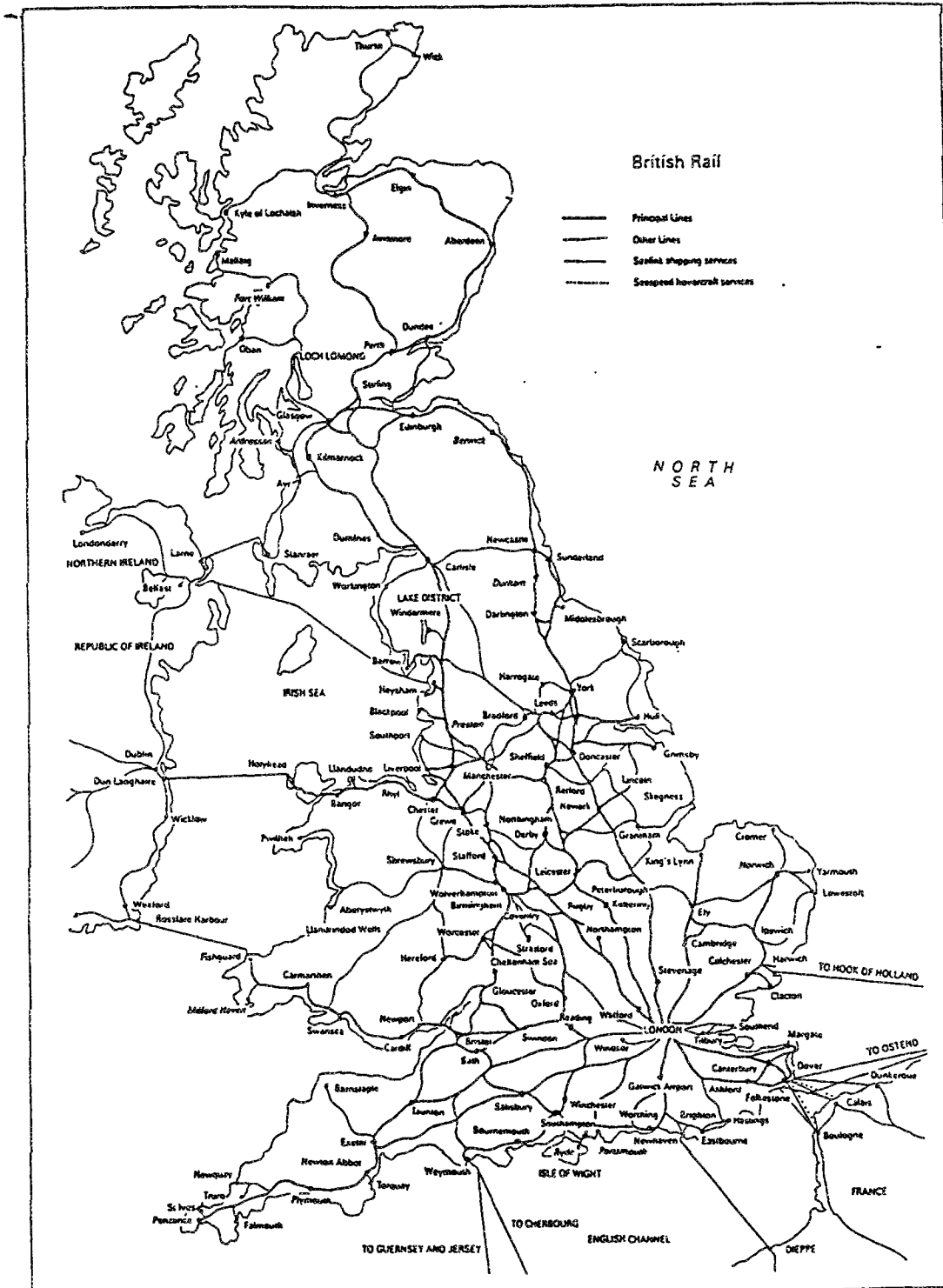
125	Diesel-powered high-speed trains; full title IC-125
225	Electric-hauled high-speed trains; full title IC-225
BR	British Rail; the state agency operating rail services in Britain
HST	High-Speed Train; term originally used for the 125 train sets
APT	Advanced Passenger Train; the BR tilt train project
ECML	East Coast Main Line (London-Edinburgh, via York/Newcastle)
WCML	West Coast Main Line (London-Glasgow, via Crewe/Preston)
Western Main Line	Rail line west from London (Paddington) to Reading, Bristol, South Wales, and the southwest of England
Midland Main Line	Rail line north from London (St. Pancras) to Leicester, Derby/Nottingham, and Sheffield

British Rail (BR) began work on improving the speed of its passenger services in the late 1960s, about 20 years after the British Parliament had nationalized the former privately owned railway companies in 1948. In this 20-year period, BR found itself in a position of declining traffic (both passenger and freight); excess track and route capacity; and ageing equipment, rolling stock, and infrastructure, much of which was due to heavy use and a lack of maintenance during World War II. After a restructuring of the traditional divisional organization inherited from the previous railway companies, BR was ready for the kind of radical downsizing and revamping proposed by Richard Beeching, who was appointed chairman of BR in the late 1960s following his authorship (with others) of the BR modernization plan, the Beeching Report, on which this restructuring was based.

The leaner and considerably smaller railway network which the Beeching Report envisaged was also intended to be a more efficient railway, with a much smaller network, faster trains, a smaller labor force, and a mission to provide service between major cities and urban regions, competing with and/or complementing other modes of transportation (primarily by road, with air competition limited to a few sectors, and canal/river transport virtually moribund). In this context, rail had been steadily losing freight traffic to the highways, and passenger services were equally threatened as the state developed a freeway construction program following the opening of the M1, the first freeway in Britain, in 1958, which went from the outskirts of London some 90 miles to the edge of the West Midlands (Birmingham) metropolitan area (see Figure 1).

The Beeching Report proposed to reduce drastically the size of the BR network, and this reflected the history of railroads in Britain. As a pioneer in railroad development with steam traction, the British had entrusted the construction of railroads to private enterprise beginning with the Liverpool and Manchester Railway in 1830. By 1850 all of the present-day main lines were opened, or nearly so, and each line required the approval of Parliament in a legislative act which

Figure 1
Map of British Rail Network in mid-1980s



Courtesy: British Rail.

gave the proposed railway company the authority to acquire land and to build. Although Parliament controlled all railway construction, the *laissez-faire* spirit of the age did not encourage much direct planning or regulation of railways. Some general legislation required a standardization of gauges, a minimum provision of low-cost passenger service ("Parliamentary trains"), but very little else.

The net result, by the end of the 19th century, was an elaborate network of trunk lines, many duplicating some of the earliest built; a full complement of secondary lines, branch lines to small cities and minor market towns; and a total domination of both freight and passenger traffic by the railway companies, who had effectively eliminated canals and rivers as competitors. Very few major British cities were served solely by a single railway company; many were the benefactors of intense competition between rival lines. A classic example of this was the competition for the Anglo-Scottish traffic (London to Edinburgh/Glasgow), the subject of a dramatic "race" between the East Coast (using the ECML) and West Coast (using the WCML) companies in the 1890s. British railway companies competed with each other, not with other modes of transportation, and the Anglo-Scottish competition of the 1890s was, in its day, a rough equivalent of a modern airfare war.

The British rail network reached its maximum mileage and density during World War I (1914-1918), and only upgrading changes and remote branches were built after 1900. The last main line into London (the Great Central Railway) was completed just before 1900. It duplicated service, already provided by other established companies, to all of the northern and midland cities it served—it was the first main line to be completely dismantled, and ended a service history of just over 60 years. Most of the older railways had been built with the limitations of the motive power of the mid-19th century in mind; locomotive tractive effort was feeble and speeds were slow. Thus, the ruling grades were frequently 1 percent or less, but curves were tight, particularly in or through towns (insofar as railways were allowed to penetrate built-up areas). This is the inheritance of permanent way with which today's BR high-speed planners have to work.

One major exception to these limitations is found in the trunk lines radiating from Paddington station in London, the terminus of the London and Bristol Railway (later the Great Western Railway). This was built to exceptionally high civil engineering standards and to a gauge of 7 feet (the widest ever used anywhere in the world) by one of the defining geniuses of 19th century engineering, Isambard Kingdom Brunel. Apart from a short stretch of 1 percent grade through a generously dimensioned tunnel, the original line is largely dead-level or with only imperceptible slopes, and it has the most generous loading gauge of any British rail line. The broad gauge lasted until 1892 (though its adoption was outlawed by Parliament in other regions after 1846), and the Brunel style of civil engineering was used on the lines running from

Paddington to Bristol and beyond to Plymouth and to South Wales. These lines are the most suitable candidates in Britain for upgrading to high-speed running.

Elsewhere, the railway companies of Britain competed over lines built on the standard gauge and with the least generous loading gauge for this track width anywhere in the world. Until World War I they had no competitors from other modes of transport, but then the age of inter-rail competition came to an end. Following direct government management of the rail system during the war from 1914 on, Parliament legislated a forced grouping of the numerous companies into four major regional systems —still private corporations—in 1921. Now many cities and metropolitan regions were served by one company, frequently operating what had been formerly rival routes. Some competition by rail survived (London to Edinburgh/Glasgow, for example), but it was now the exception not the rule. However, competition from the air was as yet non-existent, and that by road was very parochial. The size of the rail network was primarily reduced by the closure of short rural branch lines, and then frequently only for passenger traffic—the railway still could offer freight service effectively. Thus, the four regional companies which took over in 1923 still had most of their networks intact at the start of the next world war in 1939.

Events of the years 1939-1948 paralleled those of 1914-1923; government operation during the war was followed by another state-directed reorganization after the war. This time ownership was transferred to the state itself through the creation of an autonomous state agency, British Rail, which, some changes of title notwithstanding, is the agency responsible today for operating the system. The system had suffered more in this second war than in the first, but it had not been massively destroyed as had many sectors of the mainland European rail systems. Thus, the new British Rail management had an ageing infrastructure on its hands, and one that would soon be ready for both massive reductions and massive reinvestment once the impact of highway and air competition came to be seriously felt in the 1960s. BR coasted through the 1950s largely run by managers who had run the preceding companies (quite a few senior ones began work with the pre-1923 companies); its organization reflected the geographical pattern of the four previous companies—a pattern quite different from the contemporary "sector" organizational structure.

The fundamental review of the role of BR in the national transportation structure of Britain did not begin until the 1960s, when road and air were beginning to demonstrate that BR was old-fashioned, slow, oversized, and staggering about rather than striding ahead. Should the new rail network, which by any measure was going to be significantly downsized, be electrified or not? How should it strive for high speed? Was there a role for freight traffic, and if so, what kind? How should the railways be paid for: with state subsidies because they performed valuable social functions; or by the users, the passengers, and the shippers?

These latter questions were not unique to BR or the British government; indeed, they arise in almost every developed first-world economy. But the other issues facing BR concerning downsizing, the modernization of what remained, and the role of rail in a future transportation system were at a scale not equalled elsewhere. Almost no other country had created such a massive, complex, and dense 19th century network in such a small area. No wonder the future of British Rail has been one of the most vexing questions in British transportation planning for the past 25 years.

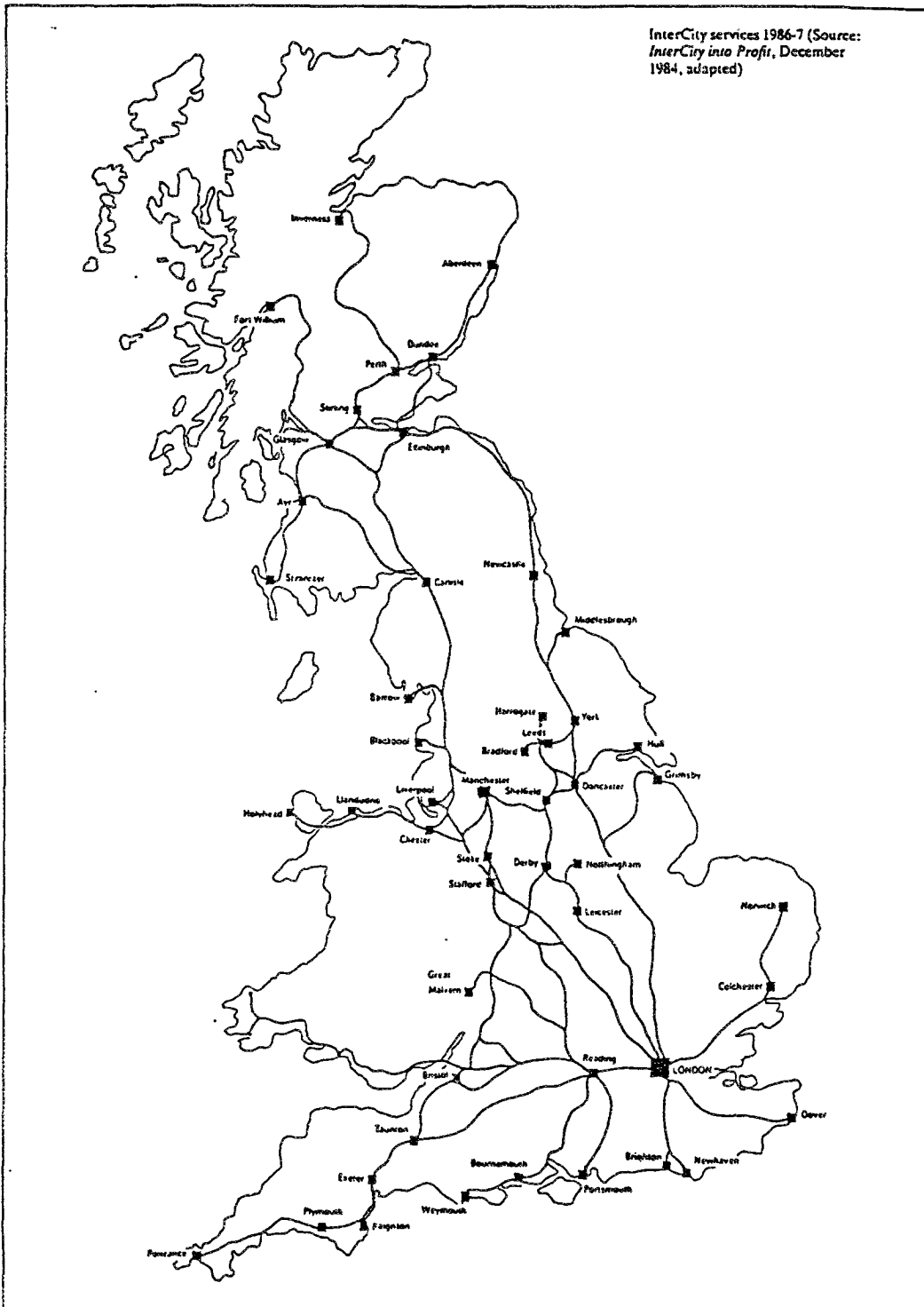
Downsizing, Modernization, and High Speed on BR since 1968

The planners of British Rail took stock of the physical features of the core system that they assumed would ultimately survive, and included future high-speed passenger trains in their plans. Although by 1968 it was clear that the state would build a national freeway road network over the ensuing 25-30 years and would thus significantly reduce highway travel times between major cities and metropolitan areas, rail still had access to central-city terminals and good linkages with local public transportation, either suburban rail or bus. Faster trains, therefore, could compete effectively with roads over distances as little as 100 miles. The problem is: how do we make the trains go faster? In the late 1960s, building new lines was not a choice. In a country as densely populated as was much of Britain, where land costs were and still are very high, this would have been an impossible financial task for a country whose economy was not growing rapidly and where there were many other demands for investment in the infrastructure. In addition, there were more than enough existing rail lines —surely the best would be kept and used more efficiently, rather than being abandoned (see Figure 2).

The APT Tilt Train Project

Out of these considerations the APT project was born. It predates the launching of the 125 HST project, and in theory is the best solution to the issue of speed on BR. Grades were mostly gentle, curves often tight, but track had been well built originally and had been usually very well maintained. The roadbed was there and was usable, but speed limitations derived from both the tight curvature and the maximum superelevation which could be used to partially compensate the lateral acceleration when transiting a curve. A tilting train was the obvious answer, and so BR authorized the start of the APT tilt train project in 1968. This was a long-term, futuristic engineering project in a very different class from the planning needed to determine the scale of the reduction of the network, the cuts in the labor force, and the more modest re-equipment needed to upgrade the surviving network. BR became and has remained the center of many economic and political disputes

Figure 2
Map of BR InterCity Services in 1986-87



Courtesy: British Rail.

since that time, responding to changes of government, restructuring its organization, and seeing the departure of the old-line railway managers. In this fight for survival the APT did not fare well.

Ahead of its time in 1968, the object of much suspicion by much of BR's leadership, and later taking on the mantle of the high-tech savior of the BR flagship passenger service, the ill-fated APT was afflicted with some serious conceptual and design flaws as a train. Although much was riding on its success, it proved an abysmal technical flop when introduced into revenue service in 1982. Never had revenue service had so short a life (literally a few days), and, following this fiasco, BR abandoned the tilt train, apparently for all time. Nevertheless, the bodies of the new 225 train sets built in 1990 are capable of being used in a tilt formation should BR once again take up the concept. BR was a true pioneer in launching the APT project in 1968, and although much of the failure can be attributed to management and organizational problems, both Sweden and Italy have subsequently shown that the technology is feasible (see Working Paper 562 in this series). Fortunately, by the early 1970s BR recognized that the development of the APT would be long as well as costly, and that a faster and cheaper interim approach to high-speed passenger rail service would be advantageous. Thus, the HST was born, later renamed the InterCity 125: a diesel-powered, fixed-formation high-speed train for use on upgraded existing lines.

The HST (High Speed Train, later the IC-125)

The IC-125, whose characteristics will be discussed in the body of this paper, was first proposed in 1970; "125" refers to the maximum speed of the HST train sets in miles per hour. It used the best of existing technology applied in some innovative ways, but its success relied strongly on the effective upgrading of the best of existing British main lines. The first 125 trains were introduced on the then Western Region of British Rail (the same main line whose central axis had been built for the 7-foot gauge by Brunel in the late 1830s) from London to Bristol, South Wales, and southwestern England in 1976. The pre-upgrade engineering of this line was such that it already saw high-speed running even in the days of steam traction; nevertheless, the 125 was a success even though the reduction in journey times over some of the relatively short distances (London-Bristol, 105 miles) did not sound too impressive.

The 125 seemed to be a worthy stopgap creating the right image for BR while they awaited the arrival of the APT, which was intended for use not on the Western Region lines (where it might have replaced the 125), but on the WCML trunk line from London to Glasgow. This line had been electrified in the late 1960s with a significant reduction in journey times over the previous steam/-diesel-hauled trains. The 400-mile distance between these two cities was the only long-distance

rail passenger service in Britain to suffer severe competition from the air. London-Glasgow was a real candidate for a true high-speed service, and the APT was clearly needed to obtain the most value from the electrification. As a success in its own right, the 125 could also be used on other mainlines, and thus it was introduced on the ECML in 1981 — on a line in which the civil engineering standards were good if not quite up to those of the Western Region main line, and where electrification had been ruled out as an investment with insufficient return. The 125 performed very well on the ECML, and this softened the impact of the failure of the APT.

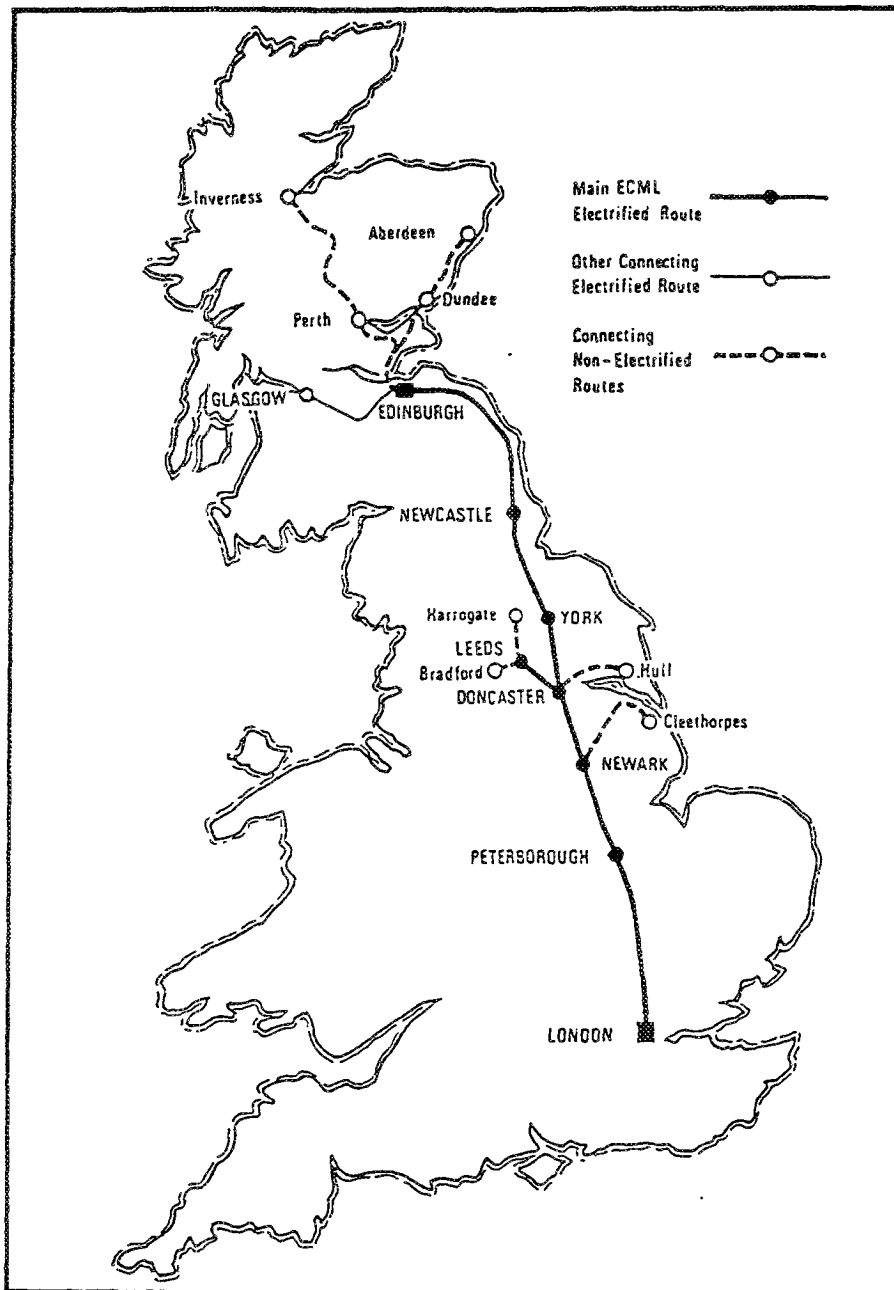
The 225 High-Speed Trains

After the APT debacle, and with declining traffic on the WCML as both air and a deregulated bus service made inroads into rail passenger loadings between London and Glasgow, BR turned its attention again to the ECML. A government unimpressed by the performance of BR in the early 1980s finally acceded to the electrification of the ECML in 1984. BR's justification of this investment was based upon a permanent-way upgrading (much of it already undertaken for the 125 services on the ECML) in conjunction with electrification, plus the introduction of a higher-speed rail service that used an adaption of the 125 technology with electric traction.

These new trains were named the IC-225 trains, a reference to their maximum potential speed of 225 kilometers per hour (140 miles per hour). Electrification was completed to Leeds in 1989, and to Edinburgh in 1990; the new service has been operating to those cities since these dates and the 125 train sets are being transferred to other provincial lines (see Figure 3).

At the time of this writing, June 1992, the 125 services are still running on the lines from London (Paddington) to Bristol, Swansea, Plymouth, and beyond, a successful operation since the late 1970s. The same train sets are also used on the major cross-country services from the west and southwest of England and South Wales (Plymouth, Bristol, Cardiff) to northern and northeastern England and southern Scotland (York, Newcastle, Edinburgh) via Birmingham. Their high-speed qualities are less easily exploited on these long semi-fast journeys, but they greatly improved the quality of the previous service. They were placed in service in the early 1980s on the Midland main line from London (St. Pancras) to the East Midland region (Derby, Nottingham, Sheffield), where high speeds were not possible but the quality of rolling stock and BR's image both improved. Following a transition period of mixed 125 and 225 use, the 225 train sets have taken over the complete operation of the ECML from London (Kings Cross) to Leeds as well as to Edinburgh in the past two years.

Figure 3
Map of the ECML Electrification Project



Source: Boocock, *East Coast Electrification*.

In summary, the evolution of high-speed service on British Rail has involved the complex interplay of these three projects. The most daring and innovative service, the APT, was the first to be launched in 1968. With future service a decade or more away and the way ahead truly unknown, BR went for the stopgap HST/125 project in the interim; a project short of technical innovation, although a sufficient success commercially to enhance both the profitability and the image of BR in the early 1970s. As work progressed on the APT, troubled by an overwhelming array of problems in all areas (technical, managerial, and financial), there were nevertheless some salvageable technological advances which came out of the APT research, and which were put to good use in the development of the 225 trains. Thus, the 225 remains a conventional train, an apparent descendant of the 125, substituting electric for diesel traction and making no use of the more exotic features of the APT (central power car, tilting vehicles). Nevertheless, the modest gain in speed over the 125 derives in part from the experimental work on the APT.

Now in operation for almost 20 years, with no rolling stock less than 10 years old, the 125 appears a dated technology; the 225, almost brand-new and having benefitted from some very advanced research on high-speed rail done mainly in the 1970s, is not quite at the cutting edge of contemporary high-speed rail technology. The British high-speed rail systems examined below never quite match the best of today's practice elsewhere in Europe or Japan. British Rail's experiences unfortunately tend to demonstrate the limitations of trying to adapt the existing permanent way to modern demands for high speed.

1. SERVICE LEVEL

NETWORK

Density

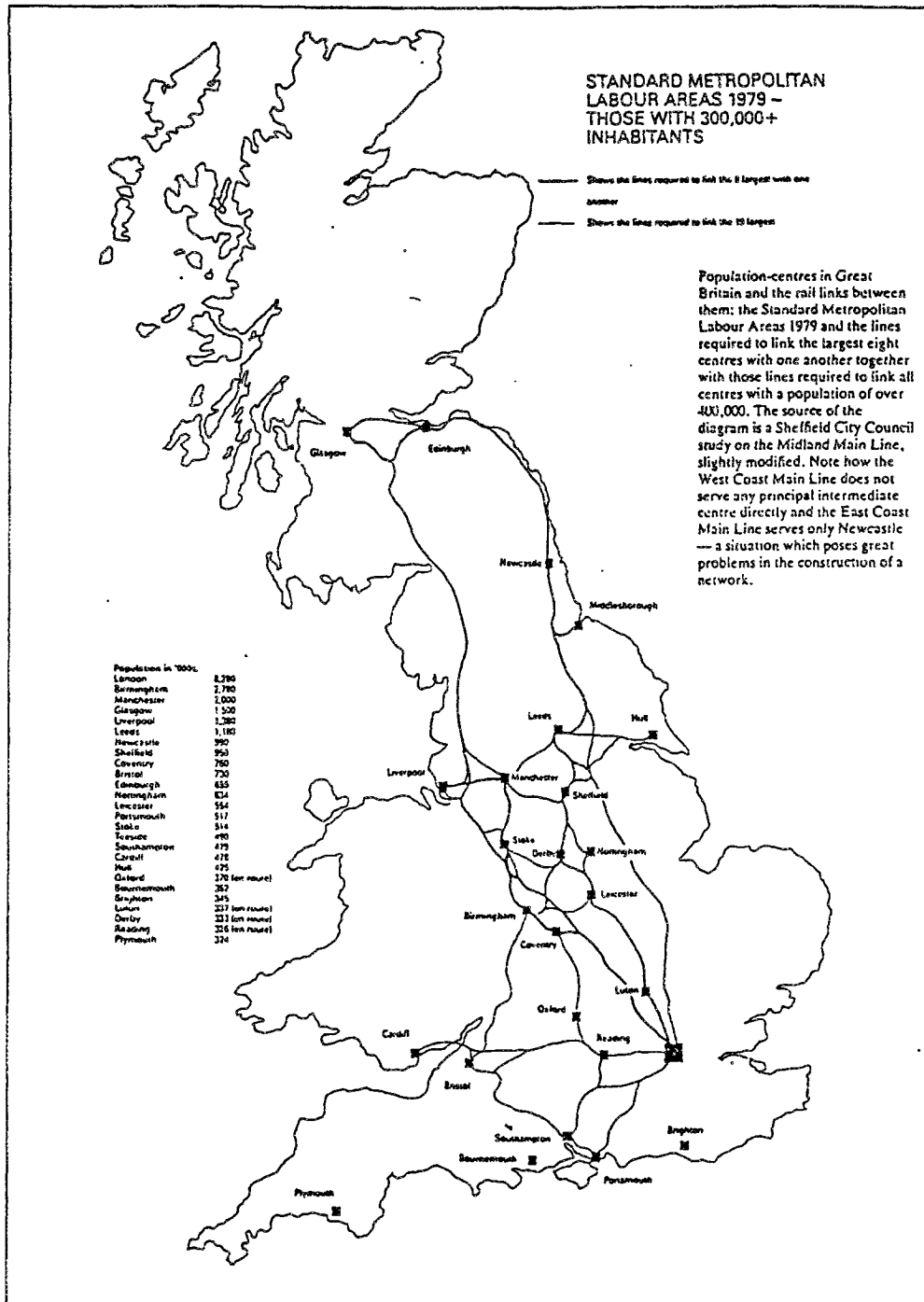
British Rail operates the rail services in all of the United Kingdom except Northern Ireland, and it is confined almost entirely to the main island of Great Britain. The rail network which survives today (1992) is but a fraction of that existing in the first decade of this century. The center of passenger rail service in Great Britain is London, the national capital located in the southeast, and containing over 10 million inhabitants, or nearly 20 percent of the national population. Passenger rail service to London from any major metropolitan area is usually more important than service between any other pair of metropolitan areas, with the exception of service between closely located pairs such as Liverpool and Manchester, or Edinburgh and Glasgow (see Figure 4).

To the south and east of London, the coast is only 60 to 80 miles distant. The eccentric position of London in the southeastern corner of Great Britain means that rail service linking the capital to the coastal cities to the east and south is essentially of a suburban, commuter type, rather than a long-distance operation. Under the present management organization of British Rail (called "sector" management by BR), this distinctive quality is recognized by placing the high-density rail services radiating out from London (roughly some 60 to 80 miles), both to the coast and inland to the west and north, under the management of the "Network South East" sector. These services attract some level of government subsidy in recognition of the necessary role they play in making the large-scale movement of people possible in London and the south east of England. None of the lines or services is in any way suitable for high-speed service in its own right. (However, a high-speed line, the British extension of the TGV Nord from Paris via the Channel tunnel, may one day be built across this area.)

From London to the north and west, the greater distances to the major provincial cities offer greater potential for high-speed service. The rail routes in this territory, beyond the operational area of Network South East, are divided operationally into three other sectors:

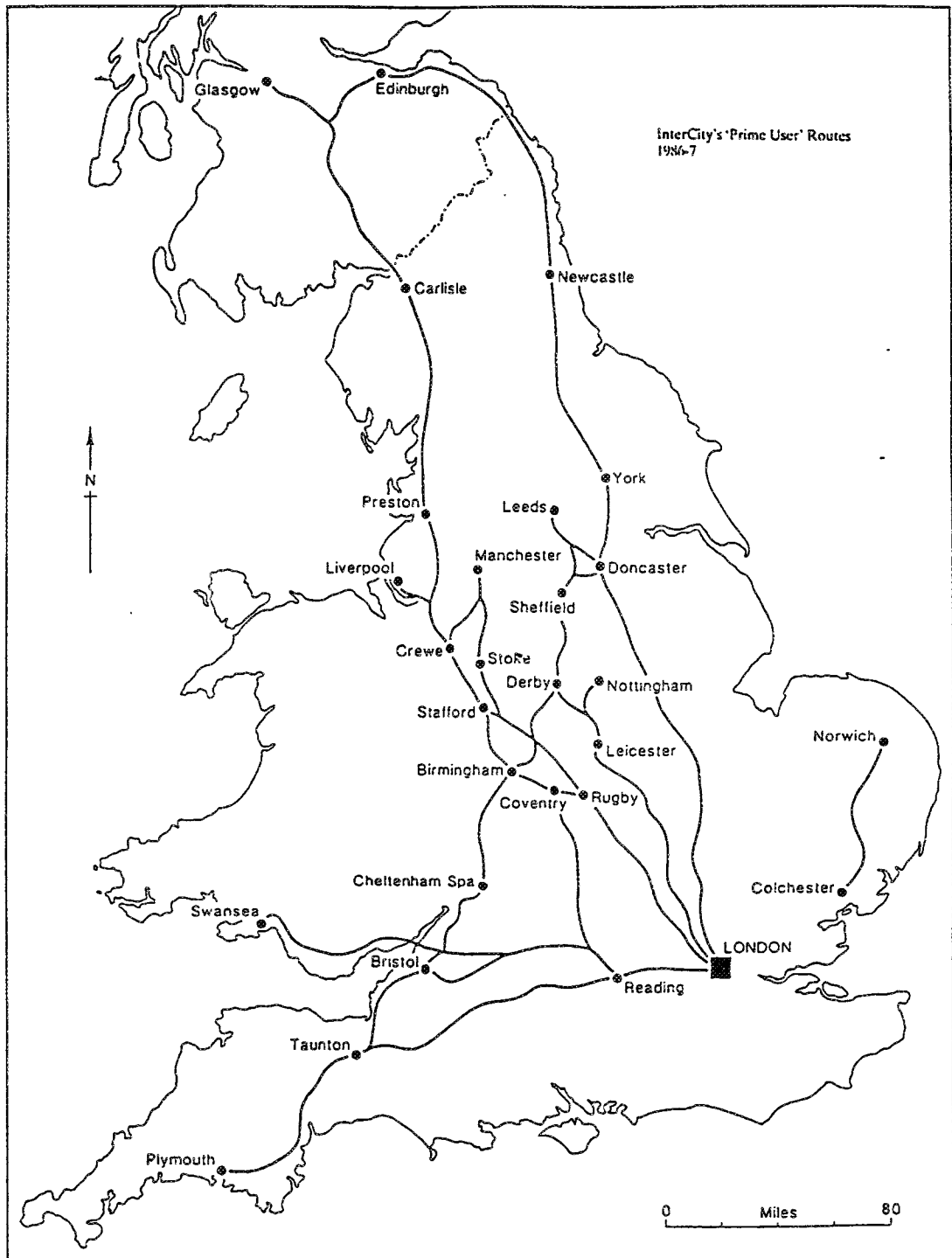
- (a) InterCity: Operates the principal main lines of British Rail, joining London with all of the major provincial metropolitan urban regions (see Figure 5).
- (b) Provincial: Operates the secondary lines outside Network South East, and retains rail service with the aid of a state and/or local government subsidy under specific conditions.
- (c) Scotrail: The regional equivalent of the Provincial sector within Scotland.

Figure 4
Map of British Metropolitan Areas and their Rail Linkages in Mid-1980s



Courtesy: British Rail.

Figure 5
Map of BR's InterCity "Prime User" Routes, 1986-87



Courtesy: British Rail.

Of these three sectors, only (a), InterCity, is expected to operate without any kind of state aid as a truly commercial enterprise, covering not only its working expenses, but expected to make a return on its capital during the 1990s. It is therefore the only unit of British Rail which has both the capacity for and the interest in high-speed services.

The InterCity sector has a basic rail network of lines extending north and west from London. The maps in the introduction show the lines comprising the sector's network. The two longest axes are the East and West Coast Main Lines (ECML and WCML). Both were built by a number of separate companies in the mid-19th century, and became the sole province of the two major new companies formed after the 1923 reorganization. The ECML became the flagship route of the London and North Eastern Railway (LNER), while the WCML performed the same role for the London, Midland, and Scottish Railway (LMS). London to Edinburgh is 393 miles on the ECML, while London to Glasgow is slightly longer at 401 miles on the WCML. Edinburgh used to be competitively served by the WCML on a spur line from Carstairs some 30 miles southeast of Glasgow, while ECML trains could easily continue on the remaining 47 miles to Glasgow.

Following the introduction of the 225 service to Edinburgh in 1991, a few London-Edinburgh trains continue on to Glasgow, taking only a few minutes longer than the WCML trains in spite of a 47-mile- (12 percent) longer journey. Flight times from London to either Edinburgh or Glasgow are exactly one hour; thus, true high-speed service with a preferred journey time of three hours or less is needed to compete effectively with the modern air shuttle operation. Currently, the fastest times to Edinburgh, using the 225 service, are 3 hours, 59 minutes (Cook Timetable, September 1991). Before the 225 service was introduced, the fastest journey times to both Edinburgh and Glasgow were over 4 hours 35 minutes on either route.

As a consequence of the way in which the principal British railway lines were built in the 19th century, both the ECML and the WCML bypass the major metropolitan regions of northern England. The most important exception is the direct passage of the ECML through the center of Newcastle-on-Tyne, the chief city of the Tyneside conurbation, 280 miles north of London. Historically, non-stop trains from London to Edinburgh passing through Newcastle have been unusual. Between London and Newcastle the axial ECML route avoids the major metropolitan areas of South and West Yorkshire by a few miles. Other important cities of northern England lie a little further from this line. Providing it has the capacity, the ECML can provide fast service to a wide range of destinations in northern England at distances ranging from 140 to 200 plus miles from London. Currently, 225 service is provided to Leeds, the chief city in West Yorkshire, which is 180 miles from London.

The WCML similarly avoids all of the major metropolitan regions of the West Midlands and northwestern England. The axial route parallels the northern margin of the West Midlands along the Trent river valley, and passes between Liverpool and Manchester via Warrington. Rail service to these areas and on to Glasgow takes the form of a central axis with loops and branches to the metropolitan regions located close to the route. Manchester and Liverpool are each 180 miles from London (almost identical to that of Leeds on the ECML). Rail has the greatest share of inter-metropolitan traffic for these mid-range (150-250 miles) distances.

The 125 service was originally introduced in 1976 on the line with the finest civil engineering in Britain: the Western Region (formerly the Great Western main line) from London to Bristol via Reading, Swindon, and Bath. The 19th century Great Western line routed all of its traffic via Swindon and/or Bristol to destinations beyond in the southwest and Wales. The excessive mileage entailed to reach many distant termini caused the Great Western Company (finally abandoning the seven-foot broad gauge) to build well-engineered direct lines and cut-offs to shorten the distances to South Wales (Newport, Cardiff, Swansea), via the underwater tunnel below the Severn River estuary. It also built lines to the southwest (Exeter, Plymouth, and beyond) via the Reading-Taunton direct line, which was upgraded and opened in the first decade of this century. These newer lines, while first-class for their time, did not match the civil engineering qualities of Brunel's original main line.

None of the cities and urban regions reached by the Western Region main line approach the size of those in the Midlands and North, the closest being Bristol with over 500,000 inhabitants, but individually and together they can generate enough traffic to make high-speed service attractive. Distances to Bristol, like those to Birmingham on a loop of the WCML, are so short (only 115 miles) that faster service tends to produce rather small time savings. In this setting the car, not the aircraft, is the principal competitor, and the express long-distance bus is an effective alternative in the public transport sector. Only Plymouth, at 225 miles from London, is far away enough for high-speed rail really to be able to show major gains in journey times, but Plymouth has only a quarter of a million inhabitants. In short, the best infrastructure for high speeds on BR did not necessarily serve the most promising areas commercially.

Integrated or Dedicated Systems

The 125 and 225 systems are fully integrated into BR's existing network, as was the abortive APT system. There are absolutely no variations in track gauge or loading gauge, and the 125 and 225 rolling stock is free to operate almost universally over the BR network. All of the upgrades to track made for the purpose of supporting the high-speed trains are equally open to use by other rail traffic.

There have been no major new cut-offs or realignments built for the 125/225 service, and many of the permanent way improvements have been built in or near major stations to speed up transit times or station operations. In contrast to the Italian and Swedish rail systems, BR has not attempted major works such as the Grodninge cutoff near Stockholm, or the Florence-Rome Direttissima.

Station Spacing and the Number of Stations

The existing lines now used by the 125 and 225 services originally had many stations serving almost any identifiable community along the route. At the same time that BR began to contemplate higher speeds in long-distance service, it was frequently able to close most local stations along its main lines because of falling traffic. The former passengers now ride the more convenient, cheaper, and practical rural bus services, or use their own cars. Thus, most British main lines now have fewer stations, usually serving country towns and cities or the suburban areas of the conurbations. In the latter case, the density of traffic has usually required the provision of two tracks in each direction; thus, local passenger service is confined to one of the pair of tracks, and in some instances platforms have been removed from tracks used normally by the fast trains. In the provincial towns and cities the stations have often had to be rebuilt to accommodate the high-speed services, a change which may usually permit through traffic to be safely separated from the platforms used by stopping trains.

Nonetheless, there remain many stations on lines used by 125 and 225 trains but which are not normally served by them —rebuilding or re-organizing the track layout has primarily a safety value, and effectively should remove the station from the impact of the passage of the high-speed train. Paradoxically, in spite of all these closures, stations are closer to one another for high-speed service in Britain than anywhere else in Europe.

The best 225 trains between London and Edinburgh (393 miles) call at York at Newcastle only, giving station spacing of 188 miles (London-York), 82 miles (York-Newcastle), and 124 miles (Newcastle-Edinburgh). Many trains on this service call additionally at one or more stations (Peterborough, Doncaster, Darlington, and Berwick are typical), and this reduces the station interval to well under 100 miles —not the most appropriate for a true high-speed service. Station intervals on the 125 service lines are even smaller:

- London-Bristol, 115 miles —all trains make four intermediate stops, which gives an average station spacing of 23 miles.
- London-Swansea, 190 miles —all trains make eight intermediate stops, giving an average station spacing of 21 miles.

- London-Plymouth, 225 miles— all trains make a minimum of four stops, giving an average spacing of 45 miles.

Almost all of the above services call at Reading, 35 miles from London. Absent the Reading stop, there would be some longer runs from London to the first stop, but none over 100 miles in the present timetables.

- London-Sheffield, 165 miles— all trains make a minimum of four stops, which give an average spacing of 33 miles. (There are a few non-stop trains as far as Leicester, 99 miles from London, which is currently the longest non-stop run by a 125 train set.)

These figures illustrate that by comparison with high-speed services elsewhere, the station spacing on BR is very close and constitutes a severe limitation on the efficiency of high-speed running.

Scheduled and Permissible Headway

The scheduled headway on most BR high-speed lines is one hour for each final service destination from the London terminus. From each London terminus there are at least two major final destinations; the interval over the axial trunk line out of London is frequently three or more trains in an hour. The working permissible headway between trains operating at the same high speed is a function of the signalling system (still multiple-aspect color light), and the braking distance of the train from full speed in an emergency, plus a safety margin. On a line in which most of the traffic has been taken over by high-speed services and with little else, the minimum headway does not have to be observed and trains can be dispatched at regular intervals. However, where other rail traffic has to be fit into the pattern of scheduling paths, the minimum headway is effectively utilized in a pattern of grouped departures, called "flights" in BR parlance (Heard, 1988: 134).

The effect of the need to integrate non-225 traffic is evident on the ECML, where the reduction of four tracks to two over Welwyn viaduct, some 20 miles north of London, requires some flight organization of the faster trains: an Edinburgh train departs on the hour; a Leeds train at 10 minutes past, following the same route for 155 miles out of London until Doncaster; and a Newcastle train at 30 minutes past. The two 125 lines from London, Paddington and London, St. Pancras have four tracks for a much greater distance from London, and, as most of their intercity traffic is operated by 125 train sets, the flight organization of traffic is not really necessary. The relatively heavy traffic that flows out of Paddington leads to 15-minute interval departures (not all slots are used) for the Bristol and South Wales services, with the Plymouth line services fitted in at 05 and 35 minutes past the hour. These latter leave the main axial route at Reading, 35 miles from London,

and from that station on they are no longer subject to the tight five-minute headway. The St. Pancras services operate at a 30-minute interval alternately to Nottingham and Sheffield via Derby.

In summary, the operation of high-speed trains can be restricted by the presence of slower-moving traffic, a situation best alleviated by the provision of four tracks (fast and slow) on a route, but without the four tracks a departure pattern using flights of departures at the minimum permissible headway (on BR's 125 trains this is five minutes in the usual minimum) goes some way to resolving the problem.

Through-Running and Connections with Other System

Because track gauge, loading gauge, and all other features of the stock are standardized to the BR norms, there is no problem of through-running; 125 trains can go where any main-line stock goes, and BR has introduced a few 125 train set services which are not able to use the high-speed capacity on lines where they represent an upgrade in comfort and quality over the previous service offered. Ultimately as the train sets get older they will be "cascaded" down to use on secondary lines; the final testimony to their through-running capacity. Indeed, the introduction of 125 train sets on cross-country routes (Bristol and the southwest to the northwest and northeast, York/Newcastle) equally demonstrates the universal through-running capability of this stock.

The 225 stock is limited to lines electrified with catenary; the only possible alternate long-distance line where it might be effectively used is the WCML, over which it could operate without problems, or isolated lines such as London-Norwich (120 miles). Many years from now it may well end up there as a result of cascading.

Until the completion of the Channel tunnel in 1993, BR's network has no physical connection with any other rail system. The 125 and 225 train sets were designed before the tunnel was decided upon, and thus no thought was given to through-running. Following the opening of the tunnel, through-running from the French TGV-Nord system will be possible. A new generation of trains is being developed quite separately for this purpose by an international consortium, and there appear to be no plans at present to send any current BR rolling stock or train sets through the tunnel after it opens.

TRAINS AND PASSENGERS/DIRECTION/HOUR

As noted in the preceding section, regular interval departures are the principal characteristic of the BR high-speed services. For the most part, the departure interval from London is hourly from

somewhere between 6 and 7 am, and continuing until 6 or 7 pm for the most distant termini, or up to two hours later for nearer destinations. The emphasis on regular time interval departures reflects the intensity of stock-working by BR, an intensity associated with the introduction of the 125 diesel sets, whose high capital cost could only effectively be paid for by high mileage use. This high mileage could be achieved through complex working diagrams.

The introduction of the complete fleet of 125 sets by 1982 and their use on the Midland main line (London St. Pancras services) — which both parallels the ECML and has easy contact points in London (St. Pancras station adjoins Kings Cross) and at Leeds (where a major service depot was established for the 125 sets) — made it feasible to have five- or six-day working diagrams using a single train set on both main-lines and even on infill trips on non-high-speed services. The more limited electrified mileage since 1990 has eliminated many of these elaborate diagrams —the electric sets are clearly confined to operation under the wires. In the 1980s British Rail was a world leader in getting mileage out of its train sets, and highly regular, fixed-interval scheduling patterns were the result.

The high-speed services in the 1990s show a little less regularity and a bit more adaptation to the market. BR serves both business and leisure travel on these services and frequently has spare capacity it can offer to discretionary travellers. Patterns of business and leisure travel are frequently distinct and can be made more so by discouraging leisure and discretionary travellers at peak business times through competitive pricing (widely used on BR in the manner of an airline and quite unlike most railway administrations, as explained later), and by the provision of differing types of supplementary service and seating (faster trains, luxury food/personal attention, more first-class space, and so on). In the end, however, variations in demand can only be met by some destructuring of the fixed-interval service. The most important observable timetable elements that reflect this reality and that are found on all the high-speed lines are:

(a) The fastest train of the day — and usually there is only one — is inbound to London in the morning, with a return working in the late afternoon or early evening. This train will also certainly feature a higher level of service (designated "Pullman" by BR).

(b) There will be one extra working out of London, with some adjustments to the normal workings, on Fridays from 3 pm onwards (the Noon-to-Midnight period on Fridays sees BR's heaviest loadings, and every passenger pays the full fare for travel during that time).

(c) Discretionary and leisure travel dominates at weekends; therefore, trains can be run more slowly and some can be dropped. However, a significant reverse flow of weekenders back

into London on Sundays from noontime on still requires some service strengthening at that time. The late Sunday flow is, however, never as concentrated as the one late Friday.

The net effect of the sensitivity to these traffic flows is the creation on many BR timetables of separate Monday-Friday, Saturday, and Sunday tables; when all seven days are combined, the tables can be very difficult to decipher. It also produces wide variations in timings over the same distance using the same equipment depending on the time of day or the day of the week— in striking contrast to the regularity of the TGV Sud-Est schedules where some day-of-the-week patterns are found, but timings are the same all through the day.

Currently on the flagship high-speed service from London to Edinburgh, the two fastest trains of the day in each direction are an early morning departure and a late afternoon return, each taking only four hours for the almost 400 miles— an average of just 100 miles/hour overall. The morning trains leave at 7 am from London and 6:30 am from Edinburgh, but the two fast return trips leave at the market-determined early time of 3 pm. The 3 pm departure from London is scheduled at 3 hours and 57 minutes to Edinburgh, which just equals 100 m/hour, and these four trains run through to and from Glasgow, taking 5 hours to that city. This is as fast as the best train on the West Coast route from London (Euston). The four best trains are also formed of the "Pullman" rakes, with a higher proportion of first-class seating (see passenger services detailed later). These four trains call at York and Newcastle only, but other trains throughout the day take from 15 to 45 minutes longer with only one or two more stops; a feature not easily explained. Leeds has a similar exceptionally fast morning and evening service in each direction, taking just over 2 hours (the fastest are the two London-bound trains from Leeds, scheduled in 1 minute under 2 hours).

The switch to 225 trains has reduced the former, more elaborate 125 high-speed service to more distant or branch destinations. Aberdeen formerly had a number of through trains which continued on beyond Edinburgh; now there are only two through trains a day, which use older, refurbished 125 train sets. These make the London-Edinburgh run in 4 hours, 25 minutes (over 10 minutes faster than the pre-electrification timings) at speeds they did not operate during the 125 regime on the ECML. Inverness still has a daily through train via Edinburgh, and Hull (30 miles east of the ECML from a junction at Doncaster) has three London-bound and two outbound through workings by 125 sets. Thus, in the absence of a complete electrification, one can either retain some mixed diesel and electric workings or lose some of the appeal of convenience. The high-speed 225 trains still provide fast service to destinations such as Hull or Aberdeen, but the flexibility that diesel operation allowed has now been much reduced. While the Aberdeen and Inverness through trains clearly are not scheduled for business traffic, the Hull timings are obviously designed to offer the most convenient service to business travel from Hull to London,

using 125 sets to avoid a change of train at Doncaster, which would not only be more inconvenient, but would lose the time gained on the faster journey from London to Doncaster.

On the ECML the distances involved for the bulk of the London-provincial traffic do not inspire competition with private automobiles. When over 150 miles long, the train usually wins for speed and comfort, and does not face air competition for business travel until distances are over 250 miles. Leeds, York, and even Newcastle fall into this reasonably protected zone, so business traffic can influence timetable patterns and discretionary traffic lured by pricing from the normally much cheaper long-distance buses. To Scotland the journey times by rail make air an effective competitor, hence business influences and effective high speed become really important elements in timetable planning. The private car is no real competitor, and a fair amount of discretionary traffic can be lured by competitive pricing from the much cheaper long-distance bus operators, whose journey times are over twice that of the fast trains. Thus, with an emphasis on business travel in the timetable, BR can still maintain a full set of train diagrams and adequate passenger loadings throughout the day.

The 125 services still operating on the Western and Midland main lines generally join London with cities in the 120- to 180-mile range, which at the lower end meets competition from the private car. Here shorter journey times impose a frequent structured time interval service throughout the day; the original considerations of maximum utilization of the costly diesel sets are still valid. Thus the Bristol, South Wales, Derby/Sheffield, and Nottingham services are very regular indeed; an hourly interval from 6-7 am to 7-8 pm is the norm, and there is only slight emphasis (in part via level of service offered and in part by a slight speeding up of the trains) on business travel during the classic early morning and late evening hours. The 7:20 am train from Sheffield makes the London run in 2 hours, 8 minutes (more usual is 2 hours, 20-25 minutes) and is the only non-stop train from Derby to London, omitting what is otherwise an obligatory stop at the equally important city of Leicester.

Only the service to Plymouth (225 miles from London), and the gateway metropolis to an area with a high volume of leisure travel, shows some major variations from the typical 125 regular interval service, with an extra train each way and other service modifications on Friday and Sunday afternoons and evenings. Plymouth is given one enhanced and faster business train into London in the morning taking 3 hours exactly (3 hours, 20-30 minutes is the norm, but there is another 3-hour train); and one return in the late afternoon in 3 hours, 5 minutes. Plymouth is at a distance which makes air competition ineffective and bus competition diminished except for those discretionary travellers who trade a much longer journey time for a much lower price.

In summary, BR service patterns on the ECML are not as structured as they were when 125 sets provided the entire service; they do not match the timetable regularity and speed consistency found on lines with dedicated high-speed sectors such as those in France or Germany, but they have a high level of frequency and face classic problems of scheduling and on-time service associated with an integrated rail system whose trains may run at very different speeds (see earlier section on Headway).

Ticket Distribution

British Rail has no special automated ticketing systems in use at present. Seat reservations are not compulsory on any high-speed service, though they are highly recommended. Some forms of capacity control through free reservations and train assignments are used on summer weekends, and these will affect some high-speed train operations, but they are not integral to them. As examples, the tourist traffic to southwestern England in the summer has led BR to institute a train pass system (not a specific seat assignment) on Saturdays in July and August; all seat reservations are free on the ECML for the three-day weekend holiday (August Bank Holiday) at the end of August services to prevent gross overcrowding. Otherwise, ticket and seat reservation systems seem somewhat old-fashioned when compared with some state-of-the-art European systems, and long lines at ticket windows are not uncommon. Business travellers, however, are offered a specialized service of ticket and seat reservation with monthly accounts and ticket delivery, similar to those offered by some of the airline ticketing services.

2. ENGINEERING

MOTOR

The 125 is a diesel-powered train set, whereas the 225 uses electric traction. There is nothing particularly unconventional or innovative about the motor and power system of either train. The 125 was introduced rather hastily in the early 1970s, as explained earlier, and an existing diesel motor was used and upgraded for the power car. The motors for the power cars of the 225 were developed by GE in the mid-1980s following the specifications issued by BR. They are modern motors, but were not radically different electric motors from those being built at that time.

The 125 Motor¹

The basic power unit of the 125 is a 12-cylinder (V12) diesel rated at 2,250 hp; the electrical output was initially rated at 1.86 kW, but after a few years the motors were downrated to 1.68 kW. It was an upgrade of a design of the Paxman company, the Valenta, and as such it had already been tested and used by British Rail. The motor had a very favorable output-to-weight ratio compared with the diesel locomotives then in service on BR, but in order to achieve the speeds needed, its capacity was increased by the use of turbochargers. Furthermore, the weight of each power car was reduced by the use of alloy solid wheels and hollow axles. The overall weight of the train was nearly 20 percent less than trains with comparable seating capacity, but each seven-car train set needed a power car at each end to achieve the design speeds—thus power output per seat was high (see Figure 6).

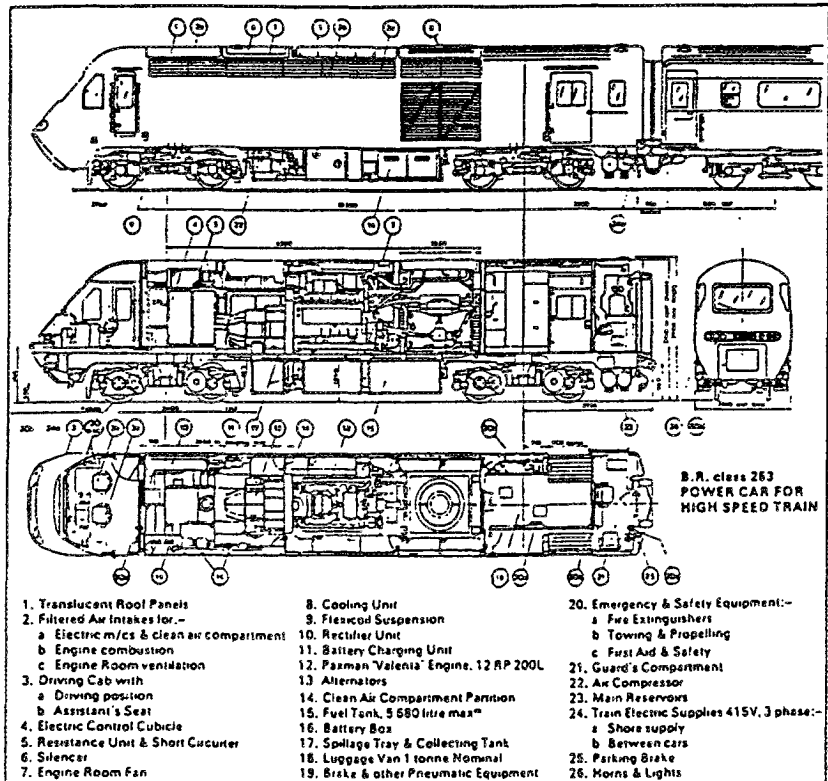
The electric motors were mounted on the bogie frames following a successful use of this technique on a recently introduced electric locomotive. The objective with all of these devices was to minimize track damage and rough riding (hunting) at high speed. There was no reason for BR to believe that the new 125 train would not work perfectly well, and so it did, but it turned out to have higher than expected maintenance costs (see below).

The 225 Motor

The 225 power car was provided with a newly designed electric motor when BR set out performance objectives for the London-Edinburgh high-speed service following government approval in 1984. The motor was designed by GE and is based on an evolution from traditional design. The motors are single-phase with six poles, in contrast to the widespread adoption in

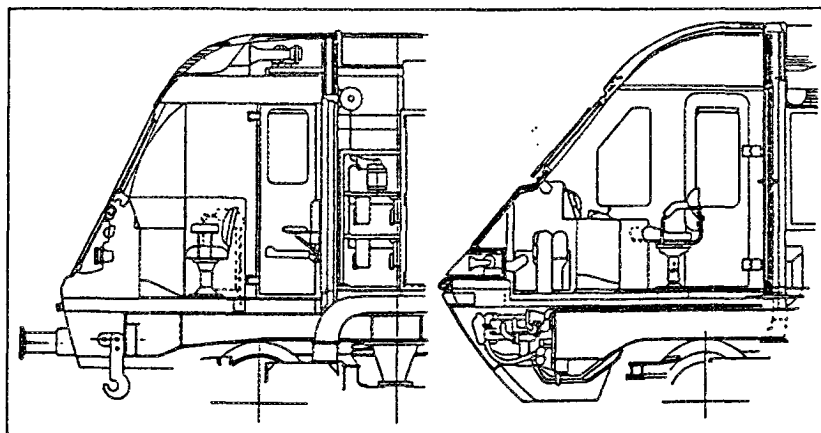
¹All references in this paragraph are in the past tense because the engine is no longer built.

Figure 6
Plans of 125 Locomotive and Motor Layout



Above BR Class '263' power car for HST.

Below left HST prototype power car cab Below right HST production power car cab with air conditioning equipment in the nose.



Source: Nock, 1983.

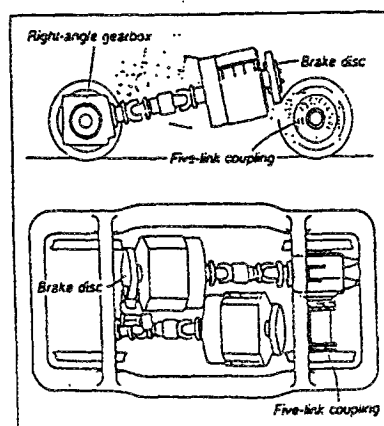
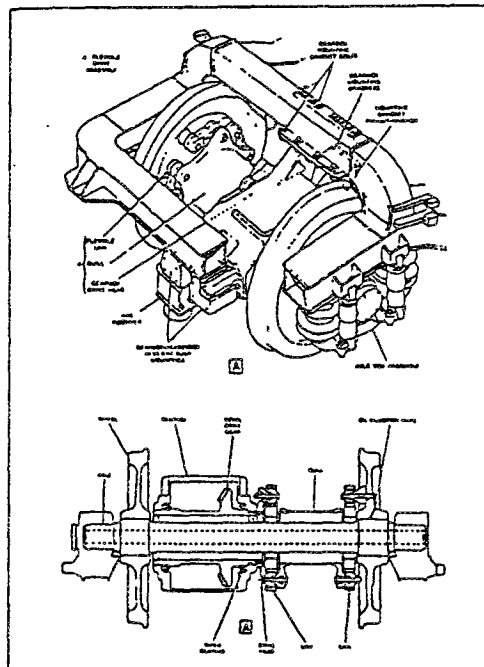
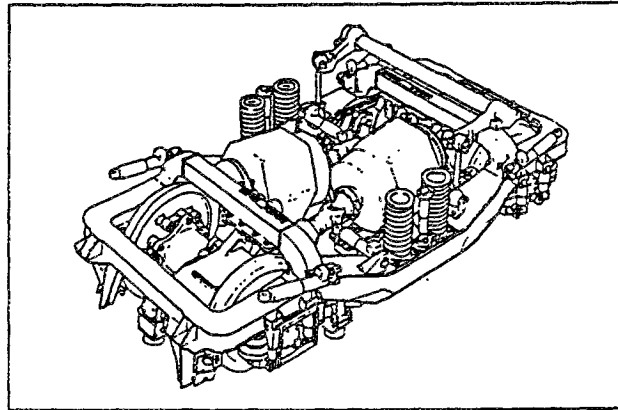
recent years of three-phase motors. They are rated at 1.175 kW, one per axle on a Bo-Bo locomotive, giving a total power of 4.7 kW per power car. The 1.175 kW rating per axle is one of the highest on European railroads (RGI, April 1987: 328). The motors are mounted directly on the locomotive body, but very low within the bogie frame. The drive is a short flexible shaft to a right angle gearbox, somewhat unusual for motors of this power (see Figure 7). The power is delivered at 25 kV overhead catenary in conformity with BR (and common European) standards for mainline electrification. The locomotives are capable of operating eight- or nine-car trains at up to 250 kmh (150 mph), in a push-pull formation with a streamlined driving trailer at the other end. One very unusual feature of the power cars is the incorporation of a driving cab at the blunt end of the locomotive. This enables it to be uncoupled and driven from either end so that it can be used on non-225 services (freight-train haulage at night, for example).

ROLLING STOCK (WAGONS)

The rolling stock for the 125 and 225 trains are identified by BR as Mk3 and Mk4 vehicles, respectively. The Mk3 vehicles were designed especially for the 125 train sets: non-articulated steel-bodied cars each weighing 32 tonnes (35 tons), and 23 meters (75 feet) long. A standard body shell was used for both first- and second- (standard) class vehicles, with the window openings corresponding to the pitch of the first-class seating. The cars were fully air-conditioned, a first on British Rail, and no windows opened. Interior vestibule doors were opened by standing on the mat in front of them. Seating was face-to-face in open vehicles. As railway passenger vehicles they were a very distinctive design change from the traditional British compartment car. The cars ran on newly designed bogies (trucks) which proved to be reasonably successful (see Figure 8). To both improve appearance and reduce air resistance, the car undersides were hidden from view by continuous panelling between the bogies. Perversely, one traditional British passenger car feature was retained: the swinging-open slam door in an era when sliding or plug doors controlled by the train conductor were widely in use elsewhere in Europe.

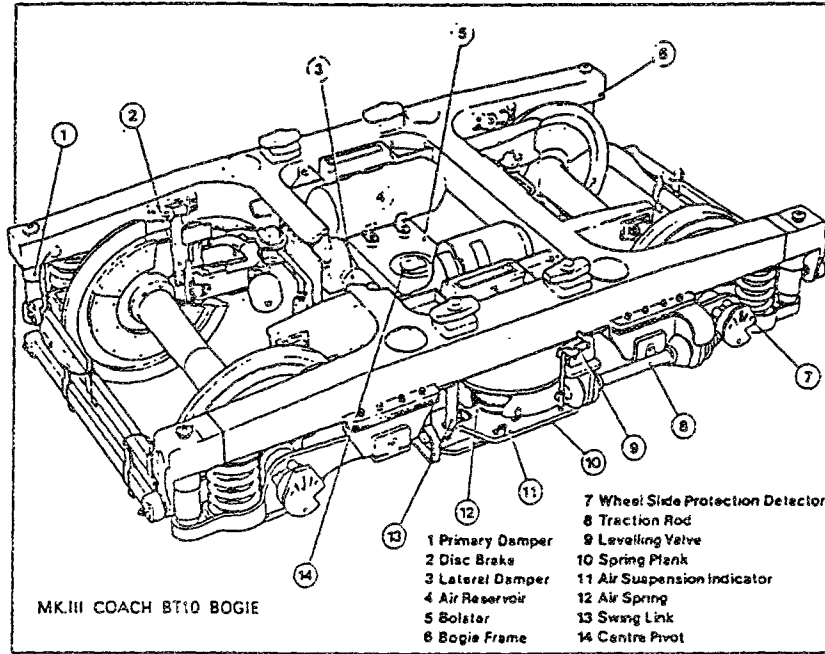
The 125 trains were of fixed formation—the original pattern used on the Western Main line was seven cars; two first, four second, and a TRUB or TRUK between them. The TRU (standing for Trailer Unclassified) was a catering vehicle with either a buffer for snack service (TRUB), or it had a kitchen for meal service at the seats in the adjoining first-class cars (TRUK). Although cars could be individually removed, the formations were never varied in service—the whole operation ran on long and tight diagrams on the minimum of rolling stock. The Mk3 vehicles became the standard for BR long-distance trains in the later 1970s and were found in locomotive-hauled formations on other lines. In both 125 service and in use on classic train formations, the Mk3 vehicles had

Figure 7
The Power Bogie of the 225 Locomotive
and an Overview of the 225 Locomotive Bogie and Right-Angle Gearbox



Sources: Semmens, 1990: 154-155;
 RGI, April 1987.

Figure 8
 Diagram of BT10 Car Bogie Designed for the 125



HST coach bogie.

Source: Nock, 1983.

standard buckeye couplers. As purely high-speed passenger vehicles, the 125 sets had almost no space for unaccompanied baggage, parcels, etc., a limitation in capacity which proved to be a real problem in the long run.

The 225 rolling stock is a direct descendant of the 125 and is identified as Mk4. The cars are visually very similar to the Mk3 vehicles; the main difference being the inclusion of sloping upper-body sides designed to allow a 6° tilt should the tilting train (APT descendant) ever be revived (see below, this section). The cars run on proven SIG bogies— an air-sprung type with features originally tested in the articulated bogies of the APT. These were designed and built in Switzerland, and were used in lieu of British-designed BT10 bogies from the 125 cars which did not fully meet the ride-quality specifications. Additionally, the lightweight aluminum bodies of the short-lived APT vibrated excessively in service; therefore, like Mk3, the Mk4 bodies are made of steel. The standard cars weigh 41 tonnes (1,200 lbs per seat in standard class), they are air-conditioned, the vestibule doors now open with a touch button rather than standing on the door mat, and the internal layout in standard-class is a mixture of face-to-face and airline style face-to-back seating in an open saloon (RGI, April 1988: 235). However, one more row of seats has been squeezed in to raise the capacity to 76 in standard-class, while the window spacing remains geared for the first-class seating pattern (first-class vehicles have 46 seats per car):

However, seat pitch is so tight in standard class that a reasonably tall person would suffer acute discomfort on a long journey in face to back seating (RGI, November 1989: 831).

The exterior design follows the Mk3 example with streamlining panels covering the mechanical equipment, but at last the outward-swinging slam door has been replaced by a conductor-controlled plug door.

The normal formation consists of nine vehicles; two first, six standard (now usually designated tourist class), and a catering vehicle with first-class style seats. The cars in each train set are close-coupled to minimize shocks on braking, instead of the traditional buckeye automatic coupler. A few trains will be composed of three first and five standard cars, and two other sets of three standard, three first, and two catering vehicles, one of which will be marshalled within the first-class section of the train and will be exclusively for first-class service. These last two rakes are designated "Pullman" by BR and are intended for "prime business services" (RGI, April 1988: 233) (see Passenger Services below). The train is adequately powered by the single power car and is driven from DVT (Driving Van Trailer) when pushed by the locomotive. Current British law does not allow passengers in a lead vehicle at high speed; thus the entire driving trailer is used for baggage and parcels, which gives the 225 train sets an excess of baggage space—in contrast to the underprovided 125 sets.

The incorporation of sloping body sides to the Mk4 cars for future adaptation to tilting operation was paralleled by the incorporation in the power cars of a power supply for active tilting of the cars (RGI, April 1987: 228). The 225 cars will have a maximum possible tilt of 6°, compared to the 9° incorporated in the original APT tilting trains. Thus, the body side panels do not slope inwards as markedly as they did on the APT train sets, and there is less impact on the interior space in the Mk4 cars; however, the impact is noticeable nonetheless. There are no immediate plans to change to tilt operation, but the original plans for renewal of the WCML, the line which the ill-fated APT was to have run, still contemplated future tilting train operations (RGI, November 1989: 831). These will now probably not be introduced at all; thus the tilt body style may be pointless (see last section).

TRACKS

British rail operates on the standard gauge, 1.435 m. (4'8-1/2") but with a smaller loading gauge than all other European railways. The introduction of 125 high-speed trains on the ECML and the Western Region main line has involved major expenditures on alignments and improved layouts, of which a minimum amount ought to be undertaken prior to the introduction of the high-speed service, but much of which can be added incrementally later. Given the existing high track-maintenance standards on the two original 125 high-speed routes, the investment went more heavily into modifying track layouts at stations and upgrading switches and high-speed junctions (see Figure 9).

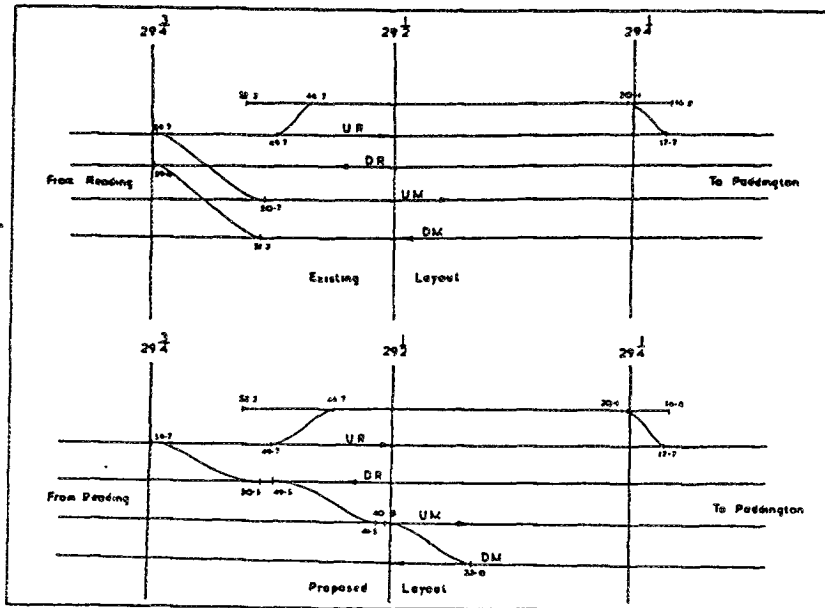
The decision to electrify the ECML has meant a much more substantial investment in raising bridges for clearance for the catenary, and because the InterCity sector desired to keep electrified track mileage at a minimum, many major station layouts have been drastically simplified — notably York and Newcastle (Semmens, 1991, Ch. 7: 114-141). Finally, where four-track main lines are used, the ability to switch from fast to slow is essential for efficient operation (avoiding blockages, permitting civil engineering work, and so on), and many of the crossover switches have had to be altered to allow high-speed transit at the junctions. The plans for the new layouts at York and Newcastle, and the plan for Ruscombe junction on the Western main line, illustrate these changes.

CONTROL SYSTEMS

Central Control

BR has not developed its train control systems to match the speeds the 225 trains are capable of on the ECML. Experience shows that speeds of over 125 mph prevent the drivers of trains from safely observing lineside signals — thus it is imperative that high-speed services use

Figure 9
Plan of Original and Redesigned High-Speed Crossover on Western Main Line



Above Western Region: Ruscombe Crossover (29½ miles from Paddington) showing the original layout (top) and the present layout with high speed crossover roads (bottom).

Source: Nock, 1983.

instead some kind of cab signalling controlled by centralized train control. Whereas this is a sine qua non for dedicated high-speed rail lines, it is an expensive addition to integrated systems if the majority of trains are still running at speeds where lineside signalling is adequate. BR had spent large sums in the 1950s and 1960s to introduce multiple-aspect color-light signalling controlled from a few power boxes, and which provided very safe levels of protection at the prevailing speeds. This equipment was life-expired and in need of major upgrading by the 1980s; thus the capital program approved for the 225 rail service in 1984 included about 10 percent of the total for a thorough modernization of the train control (signalling) system, with new central control boxes at York and Newcastle. Major reorganization of the track layouts at these two stations and elsewhere on the line were undertaken in conjunction with the re-signalling (see Figure 10).

Unfortunately, as the braking distances of high-speed trains increase exponentially with linear increases in running speed (see below), very fast trains soon exceeded the protection capabilities of the most sophisticated multiple-aspect color-light signalling. Moreover, at speeds over 125 mph the driver can no longer be assured of being able to see and read correctly the lineside signals. Above this speed, cab signalling becomes essential. The four-aspect, four-block system now in use on the ECML is not safe for trains running over 125 mph (200 kmh), and although they are capable of 225 kmh or even 250 kmh with some modification, the 225 train sets will be limited to 200 kmh — the speeds at which the 125 trains could operate— for some years until centralized/automatic train control (CTC/ATC) is installed, probably in the mid-1990s. A fifth aspect signal (a flashing green) was added for experimental high-speed running at 140 mph on a few sections of the ECML in 1989, but it was never approved for revenue-traffic operations.

Vehicular Control

The diesel and electric locomotives have conventional systems of train control typical of modern equipment. Other than the need to introduce ATC as noted above, the vehicle and power-car controls on these trains remain classic.

Station Control

With high-speed trains passing through existing stations, there has been a need to rebuild and sometimes remove platforms adjacent to tracks used by the 125 and 225 train sets. Within the major stations served by the 125 and 225, rebuilding station layouts has simplified train controls and made the stations more efficient and safer. Other than these improvements, station operations in Britain are similar for all rail services.

3. PERFORMANCE

VEHICLE (TRAIN)

Maximum Speed (Acceleration/Deceleration)

Acceleration and Speed

The 125 and 225 trains were designed for the maximum speeds that their names identify. The original HST (High-Speed Train) of the early 1970s was renamed the 125 when revenue service began, because the maximum operating speed was 125 mph. The prototype HST (125) train set achieved a maximum speed of 230 kmh (143 mph) during its trials; this remains a world record for diesel traction.

The 225 was so named because its maximum operating speed is 225 kmh (140 mph). The choice of the train designation in kilometers per hour may be viewed as a public relations trick. Over the 15-year interval, the maximum possible speed of BR's high-speed services has only increased by just over 8 per cent (15 mph increase on 125, to raise the maximum to 140 mph; hardly a quantum leap forward). When the HST was renamed the IC-125, Britain had just entered the then European Common Market and metric measurements were only used in the scientific world; today, after 20 years in the European Community, metric measurements are now common (but not for travel distances), and thus the switch to 225 (140 miles equals 225 kilometers) is a useful marketing tool—it picks up on the euphony of 125, makes the speed advance seem numerically more important than it is, and may appear to be a step in a series of advances, just as Boeing 757s and 767s follow in the series from the successful 747. Unfortunately for BR it is very unlikely we shall see a 325 train unless a new dedicated system is built—we are still some years from operation at a speed of 225 kmh.

The official maximum acceleration rates of the 125 and 225 trains are not available in the sources consulted for this study. For the most part, the use of upgraded existing permanent way means that trains are rarely able to perform to the maximum when starting from passenger station stops, and thus they work well within their acceleration capacities. The first production-series 125 train sets were put through trials in 1976 (before beginning revenue operations on the Western Main line) on the longest straight stretch of track in Britain, 18 miles within the 30 miles from York to Northallerton. From a standing start these trains regularly reached 100 mph in 3 minutes, 15 seconds, and in a distance of 3.5 miles. Getting up to maximum speed of between 125 and 130 mph took usually another 3-4 minutes over the next 5-6 miles of virtually level and straight track.

The seven-car sets of the first production series were able to perform with a small margin of reserve power on these tests; in later operation with eight-car sets in revenue service on the ECML

it was noted that the 225 trains had very little margin of reserve power left when running at this maximum speed (Nock, 1983: 55-128).

Deceleration and Braking

The deceleration curve and stopping distance graph of the HST/125 in the report shows that the train was designed to stop in 1,900 yards (1.08 miles) from a speed of 125 mph, which when converted equals a braking distance of 1.75 kilometers to a dead stop from 200 kmh (Nock, 1983: 45). These are close to standard specification values on European railways; the specification braking distance for the Swedish X-2000 trains in 1988 was identical (200 kmh to stop in 1.75 km) (CalSpeed Working Paper 562, 1992: 44). The specifications of the 225 required similar performance standards, and the equipment delivered met these standards; thus, we may assume the 225 performs within virtually the same range. Given that the brakes were costly and troublesome to maintain on the 125 sets in revenue service, it seems unlikely that this deceleration performance could be improved upon (see the later section on wear and maintenance). There appears to be no problem with the braking on the 225 trains; they use rheostatic braking to bring the speed down to 40 mph and disc brakes as well thereafter (see Figure 11).

Maximum Grade

The ruling grades on the ECML and the Western main line are well below 1 percent. The 125 and 225 trains lose very little speed on the relatively short stretches of uphill travel at these slopes. Examples of timed runs show that the 125 and 225 sets on the ECML are easily able to maintain speeds of over 100 mph on the 4-5 mile climbs to Stoke summit, 5 miles south of Grantham, the steepest on the ECML with grades of 0.6 percent on both sides (there was a 105 mph limit in effect at the summit in 1989) (Modern Railways, July 1989: 340). Grades are not an important consideration in the performance of the 125 and 225 train sets.

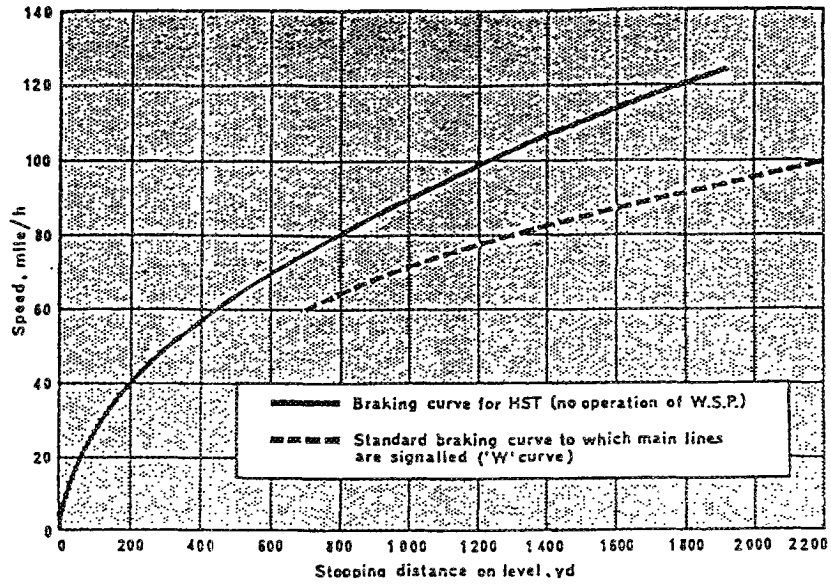
Maximum Speed/Grade/Distance

With low ruling grades, this interplay of factors is of no significance.

Energy Use

The energy use of the 225 electric trains is well within normal parameters. The newly designed traction motors are significantly lighter than earlier ones, but the delivered power at 4700kW is proportionate to the length and weight of the train.

Figure 11
Graph of Braking Performance of 125 Train
(Standard Braking Curve Shown Also)



Above Designed braking performance of the HST at 125 mph is well within the limits set for 100 mph locomotive-hauled trains.

Source: Nock, 1983.

The use of two power cars in the 125 diesel-hauled trains made energy costs an important factor. Again, the electrical rating (two sets of 1,680 kW motors, for a total of 3,360 kW per train) is proportionate to the length and weight, but the cost of generating this power was compared with energy costs for locomotive-hauled electric passenger trains on the WCML. In 1978, the fuel costs on BR were given as 44p (70¢) per mile for diesel traction, while electric traction cost 19p (30¢) per mile. In the mid-1980s the 125 energy/fuel costs had risen to £1.37 (\$2.19) per mile (which was equal to 30p [48¢] per seat/mile), whereas the electric traction costs had risen to £1.04 (\$1.66) per mile, and 18p (29¢) per seat mile (Potter, 1988: 111). In energy costs, electric traction maintained its comparative efficiency, but the global fuel crisis of the late 1970s shows in the 1978 figures—in the mid-1980s the differential had been clearly reduced. There is no reason to doubt that a similar relationship between the cost of diesel and electric energy prevails still today.

Minimum Curve Radius

Curves have been a major limitation in the improvement of speeds on BR. The first two lines chosen for the 125 service had some of the straightest track found in Britain; the Brunel-engineered Western Line had curves described as having a radius of "many miles," and the section of the ECML south of Darlington (230 kilometers from London) is almost equally well engineered, including the 18 miles of straight track between York and Northallerton. Other lines used by the 125 and 225 trains are less well-favored. The direct line to the southwest (Reading to Taunton direct), while generally well-engineered with avoiding lines built in this century past many older stations, still had odd sections of tight curves deriving from its origin as a linked set of local lines. The ECML north of Newcastle, hugging the coast, has many long and tortuous series of reverse curves with fairly tight radii—like much of the WCML, it is a line more suitable for tilting train operations.

To upgrade any of its lines, therefore, BR has had a program of easing tight curves, which in conjunction with civil engineering works to improve passage of stations, and the faster transit of junctions have gradually allowed the continuous upgrading of line speeds. There is still work to be done here; most of the ECML north of Newcastle is still limited to 110 mph, well below the capacity of the 225 trains. Clearly, the same norms, implying curve radii of 3-5 km for high-speed running at 250 kmh plus, will apply to BR in the same way they apply to other railway operators. It is, however, fair to note that exploitation of many of the lines at maximum speed is more seriously limited by the limitations of signalling and train control than it is by track curves.

Changing Train Length

The 125 train sets operate in a fixed seven- or eight-car formation with two streamlined power cars, one at each end. The passenger cars were designed especially for this service, but as non-articulated vehicles they were then adopted as the standard BR passenger car in the 1970s; ultimately, over 1,500 were built. In theory the train can be shortened or lengthened at will, but since one power car must first be detached, this is an abnormally long, time-consuming operation. More importantly, the two power cars are just sufficient for the acceleration and speeds required in service with a seven- or eight-car train. As a result, train lengths are not normally adjusted in service; each set works all of its diagrams in fixed formation; "the ratio of first to second class accommodation was fixed even though the relative demand may vary if the HST (125) operates on more than one route in a day" (Potter, 1988: 113). Of course, with complex diagrams most sets certainly operated on more than one route in any one day.

By maintaining a fixed formation for these elaborate diagrams, whose purpose is to get maximum use of the train sets, the passenger timetable writers are assured that all trains are of an identical formation. This ease of scheduling is achieved at the price of being able to adjust train length to passenger demand; "there are examples of HST (125) services being replaced by slower conventional trains because of their lack of capacity or inflexibility" (Potter, 1988: 113). With the 125 sets, BR in a sense sacrifices what little flexibility it has to change train length in order to gain advantages in diagramming. Using non-articulated passenger cars does, however, at least permit BR to remove any individual disabled car with a minimum of difficulty.

The 225 sets differ from the 125 in that the DVT (driving trailer) replaces a power car at one end. The limited electrified mileage equally prevents the sets from working very complex diagrams between maintenance stops. Nevertheless, the output of the power cars is closely adjusted to the length and weight of the nine-car trains, and it is therefore most unlikely that train lengths would be adjusted during normal operations. Two trains joined together after the removal of the two DVT vehicles would give an 18-car train, not uncommon in many parts of the rest of Europe but utterly unknown and unworkable in Britain. Once again the changing train-length feature is primarily of value in removing disabled vehicles from a working set. The cars, although not articulated, are close-coupled (as noted above) and take more effort to uncouple than the regular buckeye coupler used on the 125 Mk3 cars. Finally, as viable independent passenger cars, the new Mk4 vehicles can also be used on long-distance passenger services elsewhere on the BR network in the future.

Wear and Maintenance

BR high-speed operations have encountered most of their unanticipated costs and problems in the area of wear and maintenance; the amount of the costs of dealing with wear and maintenance have apparently been higher than anticipated — both for the permanent way and the power cars of the 125 trains. Locomotive maintenance problems for the 225 electric locomotives do not yet appear to have occurred.

Permanent-Way Wear and Maintenance

While much of the ECML and Western main-line track had been upgraded for 100-mph working before the introduction of the 125, and was by world standards well built and maintained, BR discovered very soon that 125-mph running tended to amplify exponentially any minor problems that existed in the track geometry suitable for 100 mph:

What has been observed, however, . . . is that increasing speed by 25% (i.e. from 100 to 125 mph) at the high end of the range increases the perceived movement within the coach body caused by a departure of the track from a constant geometry, to a very substantial degree (IRJ, December 1979: 42).

This is an elegant way of saying that the additional speed caused the cars to lurch noticeably on encountering minor misalignments of the track. Thus, a major leap in the maintenance of track and the parameters of acceptable track geometry were required. Since track maintenance was historically labor-intensive, the higher standards have led BR to introduce continuous welded rail (CWR), found extensively (ultimately ubiquitously) on high-speed lines, and to introduce new and very sophisticated equipment to detect track wear and to replace manual labor in maintenance activity. The network relays roughly 600 miles of track per year, and on the high-speed lines the new track is laid on concrete ties, now more closely spaced than hitherto, and on a greater depth of ballast (Nock, 1980: 33-39).

By 1979, BR had largely completed the installation of CWR with heavy rail comparable to that used elsewhere in Europe (60 kg rail per meter/115 lbs a yard) and had made a lot of progress with ballasting and tamping machines to adjust misaligned track (IRJ, December 1979: 42-44). BR also developed its own track recording car in 1977 (IRJ, March 1977: 29).

Locomotive Wear and Maintenance

The 125 locomotives have performed well, but this performance has been achieved at the expense of the power cars themselves. The Valenta diesel engines ran at higher speeds and for longer periods of time than had been envisaged by the original designers. What was a very trust-

worthy diesel engine was upgraded in output by the addition of a turbocharger, which later became a source of maintenance problems — bearing failures being common (Modern Railways, March 1979: 105), as well as gearboxes made with lightweight aluminum casings that cracked. These breakdowns most probably came from excessive annual mileage — the Australian XPT trains, which had identical engines (and steel gearbox cases) but ran far fewer miles per year, never suffered excessive maintenance problems (Potter, 1988: 110-111).

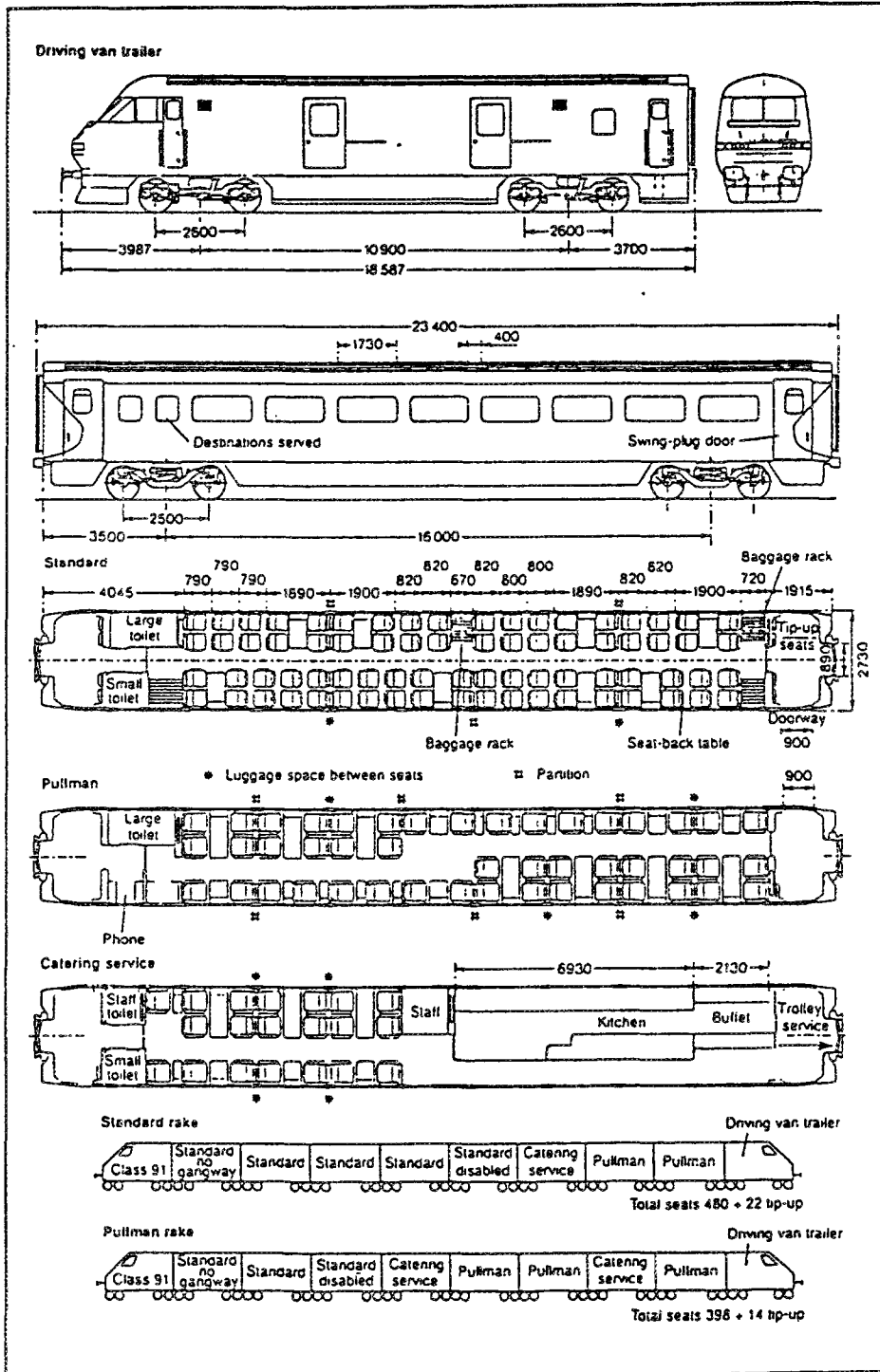
The most serious wear problems occurred on the brake gear; the disc brake pads simply wore out far faster than anticipated. They all too frequently cracked and broke, and they gave off a burning smell in use which at times penetrated the passenger cars. BR never solved these problems and simply replaced broken brake pads far more often than planned. As well as reducing the availability and reliability of the 125 locomotives, these problems have also increased operating costs through higher than anticipated maintenance costs.

Passengers

The 125 and 225 trains operate normally in fixed formations, due to motive power and diagramming reasons as noted above. The normal seven-car formation of the 125 train sets is two first-class, four standard- (second-) class, and one catering vehicle. The trains have seats for 288 standard-class and 92 first-class, for a total of 380. The ECML 125 sets normally had one more vehicle — if a standard-class, the total capacity was raised to 360 standard plus 92 first, for a total of 452 seats. The cross-country (south and west of Bristol to the north and northeast via Birmingham services) usually had only one first-class car (business travel was relatively unimportant on these lines), giving a total of 406 seats, of which 360 were standard-class.

The 225 sets have a normal eight-car formation, with one more standard-class car, than the original 125 sets. A later order was placed for 31 more standard-class vehicles to permit the strengthening of the rakes to nine cars, the maximum the locomotive can haul. The increased capacity of the standard cars to 76 seats means a normal formation has 380 standard seats and 92 first, for a total of 472. The nine-car formation would have 546 total seats. This pattern is varied in a few rakes in which one standard car is replaced by a first — 304 standard, 138 first, for a total of 442. This is significantly reduced for the Pullman formation: three first with 138 seats, three standard cars with 228 seats, for a total of 366, although the seats in one of the two catering vehicles will add another 20 potential first-class seats. Provision of varying ratios of first and standard seating leads to significant variations in the total number of seats on a train, and is an important factor when determining levels of fares and the appropriate differential between first and standard (see Figure 12).

Figure 12
Plans of the Standard Passenger Cars of the 225 Train



Source: Semmens, 1990.

The standard-class cars in the 225 train sets have high-density seating patterns (see previous section), but more imagination has been used in the layout of the first-class cars— the off-center aisle switches from one side to the other at the mid-point of each car, and the use of smoke-gray panels partitions the interior space effectively.

The only other amenity provided is the British Telecom standard "Phonecard" telephone in each car.

Handicapped Facilities

The 125 trains originally seem to have made no special provision for the handicapped— the 225 sets have a larger toilet for use by the disabled (and by mothers with babies whose diapers need changing) in each first- and standard-class car; additionally, one standard-class car per rake has a space for a wheelchair close to the large toilet. No other special provisions for the handicapped, blind, or deaf are noted elsewhere in the literature.

Amenities

The principal amenity provided on both the 125 and 225 trains is refreshment service. The BR catering vehicles used on the 125 are designated either for buffet use with 31 seats (called a TRUB; see section on Rolling Stock in Chapter Two) or with a larger kitchen (TRUK), reducing the seating to 23 (the seating has standard-class pitch, but is officially designated "unclassified"). The kitchen is capable of serving full meals. The catering vehicle is always marshalled between the first- and standard-class sections of the trains, and the kitchen version is used to serve complete cooked meals to the first-class passengers at their seats. Standard-class passengers either take food back to their seats or use the available seats in the catering vehicle. This level of service initially worked well on the Western main line, and was sufficient for journeys of up to two hours. Thus, it remains the norm for most Western and Midland main-line 125 trains, most of whose journeys are of this length or less.

The 225 services to Leeds and Edinburgh required a review of this catering provision, a service level that had already been demonstrated to be inadequate with the introduction of 125 services on the ECML ten years earlier. The new train sets have retained the same basic formation of the 125, but restaurant services to the first class are now available on all trains and are provided on journeys where there will be a demand for meals (a much higher proportion of all journeys than is true on the runs under two hours). More importantly, BR has decided to recognize a need to cater to businessmen by offering "Pullman" service, using train sets with an extra catering vehicle (three

first-class, three standard-class, and two catering vehicles). These services are summarized in the timetable leaflets which are included in this report (see Figure 13). In 1986 BR changed the organization of its catering services, removing the on-train catering on InterCity services from "Travellers Fare," the catering subsidiary, and returning it to the direct management of the InterCity sector. The sector planned to upgrade its catering services by introducing "Cuisine 2000" with "shore-based" food preparation and greater quality, variety, and choice, but this was soon abandoned for a return to meals prepared in a train kitchen. The catering services will be expected to make a profit rather than serving as a loss leader, as was the case in the past (IRJ, November 1987: 26).

Reliability

The reliability of 125 operation on the Western main line during the first two years was summarized in 1979: 20 out of 27 train sets were in service at any one time, which equals a 75 percent availability, whereas BR had planned for 84 percent (22+ out of 27 sets in use at once). Reliability was expressed as mileage run between failures which caused a five-minute delay or more to a schedule—for the 125 in 1978 this figure was 20,000 km (12,400 miles), a distance which was slowly increasing (i.e., reliability was getting better). Unfortunately, no norms were given in the article on this topic. However, this was equal to about 20 days' mileage at that time; thus 20 train sets with the same reliability factor would produce an average of one mechanical failure per day on the Western main line in that year (RGI, February 1979: 144).

BR uses standards of punctuality for rail service that make it difficult to pin down precisely how punctual or reliable their service really is. In 1986, 90 percent of InterCity sector trains arrived on time or within 10 minutes of scheduled arrival time (IRJ, November 1987: 20). In 1988 this same value (90 percent of arrivals on time or up to 10 minutes late) was the goal and it was not met; only 87 percent of arrivals qualified:

indeed, late running is so endemic that a warning appears in the latest timetable that a minimum of 15 min must be allowed for any connection at nodes like Crewe or Birmingham New Street, whereas 5 min is considered ample at Bern or Utrecht (RGI, November 1988: 737).

Furthermore, the public timetables include "recovery times" a few minutes on many working schedules. Are the working timetables or the published timetables the reference point for determining lateness?

Reasons for late running are complex, but at the heart of the problem is heavy traffic in which high-speed and slower services are mixed: over the notorious Welwyn viaduct and tunnels

on the ECML where four tracks reduce to two over a stretch of a few miles; and on the intensively used axial trunk line from Paddington to Reading, where 125 trains depart in flights close together in order to have a path open at the higher speed. The signalling systems, which in any case prevent the full exploitation of high-speed running, are all ageing; also, the basic system on the ECML is 25 years or more older, and will have to be replaced within perhaps the next ten years. Meanwhile delays due to signal failures are all too frequent.

Kilometers in Service

The BR 125 sets have achieved some remarkable mileages in service. In the first years of operation, the 125 sets of the Western main line ran over 350,000 km (220,000 miles) per year, which seems to be the norm for operations through the 1980s. This is more than twice the annual distance achieved by the standard BR long-distance passenger diesel locomotives. Many sets work over 1,000 miles a day on routes where the longest distance, terminus to terminus, is less than 200 miles. The oldest 125 sets have now been in service well over 20 years and may well have run about 4,000,000 miles in that time. Though no comparable figures are given for daily, annual, or lifetime mileages for other diesel equipment, all references to these levels of usage suggest that it may well be some kind of world record. The 225 trains are expected to have a useful life of 35 years and to run over 200,000 miles a year if needed.

Accidents

The 125 and 225 services have been remarkably accident-free. BR's network is almost entirely fenced to prevent public access, and until the 1970s all grade crossings were tightly controlled. There has been a substantial replacement of controlled highway grade crossings by automatic barriers, but fortunately this has not led to an increase in accidents in spite of public apprehension and increasing train speeds.

Platforms on stations through which high-speed trains pass are a source of danger— where trains pass at over 100 mph, a yellow line is painted to indicate a danger zone. For speeds over 125 mph, the platforms will be closed to the public and probably removed.

4. ENVIRONMENTAL IMPACTS

LAND USE

Land use impact of the 125 and 225 trains are minimal. No new lines have been built, and because BR has generally been selling surplus land over the past 20 or more years, there has been no problem in finding land for maintenance or service facility buildings for either series of train set. The remodelling of layouts at York and Newcastle stations for improved operations has generally led to a reduction in trackage. Both York and Newcastle stations are historic, listed 19th century buildings, but the remodelling has not led to any major demolition of architecturally significant structures, or to any serious disputes about them. In the past few years BR has rejected the idea of building a new, dedicated high-speed line.

POLLUTION

Major concerns such as noise, visual/barrier effects, and other environmental impacts have not been important problems in the development of the 125 and 225 high-speed systems. The two locomotives of the 125 sets are loud, but they have no worse ratings than many other contemporary BR diesel locomotives. The 225 locomotives are no noisier than any other operating electric power on the BR network. The existing lines of BR are not subject to contemporary laws concerning noise levels, but any new line would be. BR nevertheless attempts to be a good neighbor in a society where its image is not always the most favorable. As long as 140 mph speeds or higher are well in the future, BR should have no serious problems in this matter.

The use of existing lines with upgrading has not changed the visual impact BR lines have upon the British landscape. No other environmental impacts have been noted in the literature. One final improvement: the toilets are now chemically sealed, and the admonition not to use the toilet in a station has been removed from the toilet compartment - a long overdue improvement!

5. REVENUE (vs. Competing Mode)

The financial system under which BR currently operates makes it impossible to give any analysis of revenues by ticket category, passenger/mile, or train/mile. BR is expected to be an effective competitor with both highway (car and bus) and air transportation. Its financial details at this level are not available.

Unlike any other European state railroad operation, BR has been working under a program in which it will ultimately receive very little state subsidy. The division into the sector management has led to subsidies being restricted to the Provincial and the Network South East sectors, and even these may phase out or change their form. The provincial sector is already receiving more subsidies from local governments than from the national government in London. From April 1, 1988, InterCity has received no state PSO grant (Public Service Obligation). The losses of £100m (\$160m) on a revenue of £660m (\$1 billion) in 1986-87 were reduced to £46m (\$70m) two years later, and are expected to turn into a profit by 1991. Revenue covers 85-90 percent of all railway operating costs in Britain—a level not equalled elsewhere in Europe, and the product of endless cost-cutting and tight management practices developed over the past 15 years. In addition, fares are also among the highest in Europe.

The revenues of InterCity, as a result, are the product of complex marketing devices, not unlike many airline ticket marketing systems. The concept of a full fare exists, and these are quite high (London-Edinburgh is £55 [\$80] one way in standard class for a 400-mile journey), but only those who travel on busy morning trains or at any time Friday afternoons or evenings need pay full fare. Lower fares, up to 45 percent less on round-trip rates, exist for less busy periods—typically the middle of the day, the evenings, and weekends. However, each pattern of reductions is geared to the traffic on the line in question, and though they do not vary widely, these pricing patterns reflect attention to the market. Additionally, BR offers airline-type "APEX" tickets for travel at selected times with advanced purchase—conditions very similar to those of the airlines. In addition, other devices are used: weekend-first fares, for example, in which a small fee allows a standard-fare traveller to ride in first class on Saturdays and Sundays when the businessmen are not travelling. There are endless special fares for events, for promotional activities, and most recently coupons for reductions in association with promotional activities of chain stores.

Fewer special offerings are made to first-class and business travellers—the reduction in the total number of seats in one of the Pullman rakes with three first-class cars shows that each first-class passenger must pay individually far more than the average paid in standard class for the

train as a unit to earn the same revenue. Given that the high first-class fares are imposed by this loading factor, BR can only then make first-class travel attractive by quality service (food, space, on-time reliability, and so on). Although business travel is important on certain trains, the proportion of first-class tickets sold overall is under 15 percent, and the second-class passenger is more important in both numbers and revenue, hence the market-based pricing described above. Because a substantial share of business travel is in standard class, BR has now attempted to emulate the airlines with special privileges for those who pay the full standard fare (free seat reservation, free drinks and snacks), a necessary development given the deep discounting of fares for the discretionary travellers.

InterCity knows, we assume, very well what its costs and revenues are on a new service such as the 225 service on the ECML, but no details are published. The overall performance is continuously monitored by the government, which controls the amount of investment capital available to BR. The InterCity sector is now in direct competition with competing modes of transport in Britain; no recent data tells us how well it is doing, but in 1977, the first year of operation of 125 service to Bristol and South Wales, rail traffic increased from about 25 to over 30 percent of the total market on each line. Given the shorter distances involved, almost all of the diverted traffic came from previous highway users. Similarly between 1966 and 1970, following the electrification of the London-Birmingham-Manchester route which provided faster timings, one-third of the air traffic was diverted back to rail, and this accounted for equally one-third of the gain in traffic (RGI, May 1979: 409). More recently, in 1990, BR noted that it had 43 percent of the passenger movements between London and Manchester (180 mi) but only 17-18 percent between London and Birmingham (115 mi), and London-Glasgow (400 mi); to the former the car was a formidable competitor, to the latter air traffic was competitive.

6. COSTS

The total authorized investment for the ECML electrification when approved in 1984 was £306 million (\$500m); and this had grown, with the use of an inflation index, to £420m (\$675m) in 1990 when the work was almost complete. This investment was broken down into £112m for the new electrification infrastructure (wiring, power supply, and so on), and £132m for the rolling stock, of which roughly half of each was for the locomotives and the passenger cars, respectively. These amounts are for the 1984 budget, and the actual costs were divided in the same way among the £420m.

INFRASTRUCTURE

The allocation of costs for work on the infrastructure of BR prior to the introduction of high-speed service are not readily available, much of it being difficult to disentangle from ongoing investment for normal services.

Stations

The improvements in stations were not included in the original budgeted sum and clearly benefitted the operations of the entire railway, but without them high-speed service would have been much less successful. No indication of the costs of rebuilding the layouts at York and Newcastle is given in any source. Many of the other track improvements that made the higher speeds possible had been undertaken earlier and paid for separately, primarily in connection with the introduction of the 125 service on the ECML in the late 1970s, and even earlier with the introduction of 100 mph service in the 1960s.

Track (Upgraded and New)

It is impossible to find any details of track upgrade costs in conjunction with the introduction of the 225 service on the ECML.

Control System

The ECML required a major resignalling program in order to continue to operate at the existing speeds —the previous system was life-expired and incapable of continued use with electrified lines for technical reasons. Consequently, £27 million was originally budgeted for a

complete resignalling, and this was raised to £49m (\$80m) by the time the work was nearing completion. Unfortunately, the resignalling was based on the existing four-aspect color-light system, and does not permit running above 125 mph up to the permitted maximum train speed (currently 140 mph). A further investment is required, and will be undertaken in the 1990s to permit the trains to run at the speeds for which they were planned.

Power Distribution System

As noted above, the total cost of the installation of the power supply was £112m. in the 1984 budget and actually cost about 25 percent higher at about £130m (\$210m). More importantly, the cost per kilometer to install the catenary was £68,000 (\$110,000), which was almost 50 percent below what it had cost per kilometer (adjusted for inflation) to electrify the London-Manchester line in the early 1960s. BR believes this to be one of the lowest costs of installation of catenary in the world.

VEHICLES

The total cost of the rolling stock for the 225 electrification was £132m in the original budget, and this increased by 25 percent in 1989 to about £165m (\$265m). This was equally divided between the cost of 62 electric locomotives at £1.3m each and 324 passenger cars, which were budgeted at £205,000 each and cost about £250,000 (\$400,000) each when delivered. A train set with locomotive, DVT, and a full rake of cars averaged about £3.7m (\$6m) when delivery began in 1989. The cost per seat came to £8,800 (\$14,000), and BR claimed it was significantly lower than the cost per seat on any other high-speed trains, particularly the TGV train sets (RGI, April 1988: 233).

The capital costs of the older 125 diesels can only be quoted at prices which are not now relevant; more appropriate is the comparative annual capital cost calculated in 1984. An eight-car 125 set cost £1.32 (\$2.11) per mile of annual operation, and 29p (47¢) per seat-mile; the ten-car train hauled by a class 87 locomotive had a capital cost of £1.27 (\$2.03) per mile, but because it had 590 seats, 140 more than the 450 of the 125 set, its capital costs per seat-mile were only 22p (35¢). Thus, the cost of providing a seat in the 125 was 34 percent higher than in the conventional train. This difference is made more striking by an examination of the maintenance costs analyzed in a later section (Potter, 1988: 111).

PERSONNEL

There are no specific figures for the cost of personnel for the 125 or 225 services. The trains do not require any unusual levels of staffing.

MAINTENANCE

The 225 services have not yet established a track record for maintenance costs nor have they revealed any unusual problems of maintenance.

The 125 diesel sets proved to require much higher levels of maintenance than expected within just a year of going into service in 1977. In 1984, the 125 sets had established a maintenance cost profile that compared unfavorably with electric locomotives of class 87, which was then the most important electric power available on BR (the example is drawn from the same source used in the capital cost comparison immediately above).

The maintenance costs averaged £2.28 (\$3.65) per mile and 51p. (81¢) per seat-mile. The costs per mile were 47 percent higher than those for the electric locomotive, and the seat-mile maintenance costs were almost double those of the electric-hauled train (one electric locomotive did basically the work of two of the diesels). These high maintenance costs were a result of heavy engine use which caused rapid wear of some important mechanical parts (as noted in previous performance sections). Paradoxically, the heavy maintenance problems resulted from intensive working diagrams which in themselves were necessary to generate the revenues to pay for the maintenance. It was an unusual, closed economic system.

7. SYSTEM STATUS

RESEARCH AND DEVELOPMENT

The major work on the 125 High-Speed Train was done by British Rail itself in the early 1970s, and it was associated with the work just started on the APT. At that time BR ran its own Research and Development operations, and although the 125 was a success, the APT proved to be a dismal failure, in some measure due to the management/structural problems within BR. (While not directly germane to this report, it should be noted that an inappropriate organizational structure can bedevil a long-term technical project of this kind; see Potter, 1988, and Potter, 1989.)

The 225 project was undertaken in a manner more typical of modern high-speed rail development. By the mid-1980s the engineering departments (locomotive- and wagon-building) had been privatized as BREL (British Rail Engineering Limited), and were now expected to survive as a competitive rail engineering enterprise without privileged access to BR work. Thus, locomotives and rolling stock were to be developed in a way new to BR. BR formed a Project Team for this purpose; the team, under a director and with an all-important engineer project leader, went to work on the specifications for the new trains with some decisions already made.

Two firms bid on the contract in its closing stages: GEC of Britain, and ASEA of Sweden. GEC won the final contract. GEC has subsequently become part of the international GEC-Alsthom consortium, while ASEA has linked with Brown-Boveri to form the ABB international engineering firm. The international contacts and resources later provided by the mergers would enable either firm (GEC in this case) to design to a specification faster than the old in-house engineering department. The building of the 225 trains — particularly the locomotives — has become a joint enterprise, in effect, of a government agency (British Rail) and private enterprise.

On the other hand, the civil engineering required for electrification was still largely in the direct hands of the BR managers — but it was certainly in their interest to demonstrate to a skeptical government that they could handle the permanent way work most efficiently at least cost. Until and unless Britain adopts the Swedish model of separating train operations from track ownership (and it is an idea being considered as part of possible privatization proposals for BR in the 1990s), the rail agency itself has to look after the trackwork.

Although it is not the complete in-house research/development system BR had until as recently as 15 years ago, the new method of developing high-speed services is still not as open to the role of private companies (GEC-Alsthom, ABB, Fiat-Ferrovialia) as the systems found elsewhere in Europe.

Current Use

The current use of the 125 system is by BR, with a limited use by the State Railways of New South Wales, Australia, who use a direct copy of the locomotives with fewer cars, called the XPT, on services within the state to destinations about 4-5 hours from Sydney. Australian service was not at the speeds found in Britain, but it was a stylistic improvement on the equipment which it replaced. Much less intensive use of the XPT equipment gave the Australians almost none of the maintenance problems found on BR's 125 sets.

The 225 is used only in Britain. It would have no applications on other European high-speed lines, but probably contains engineering features which might make it of value on lines of lower speeds in Europe or elsewhere in the world.

Near-Future Use

Currently, there is no evidence that any rail system anywhere is testing the 225 for high-speed service; it is not as fast or as technically advanced as the competing European high-speed trains. On integrated high-speed systems, the tilting trains of Italy and Sweden offer greater possibilities for the immediate future and have been "borrowed" for testing.

Although the 125 was the world's only diesel high-speed train, and although it holds the world speed record for diesel traction, it has no prospects for future use in its present form. A 20-year-old design, it is no longer state-of-the-art, and it is probable that the relatively high capital and maintenance costs, when compared with traditional locomotive haulage, did not make it attractive elsewhere.

British Rail, therefore, does not apparently have a marketable technology in either its 125 or 225 high-speed formats.

Since 1989, BR itself has been looking at the WCML, the line on which the APT was to have run. The modernization which came with electrification in the 1960s is now life-expired and substantial sums will be needed to upgrade the signalling and train-control systems. After much study, BR has rejected the idea of building a new dedicated line for any part of the route. Instead, it is promoting the concept of the IC-250, a train with a planned speed of 250 kmh (155 mph) on the WCML, using upgraded tracks. Absent the tilting train, BR has decided to relax cant deficiencies so that the present curves can be traversed at higher speeds, but without the investment in ATC (cab signalling) it is difficult to see any increase above the present limit of 125 mph. The WCML is not even at that level yet, and considerable upgrading of the permanent way is needed even to match the present ECML speeds. Thus, the goals of first 140 mph and then 155 mph seem very far off indeed (RGI, April 1991: 223-227).

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