Railway Technology—The Last 50 Years and Future Prospects

Roderick A. Smith

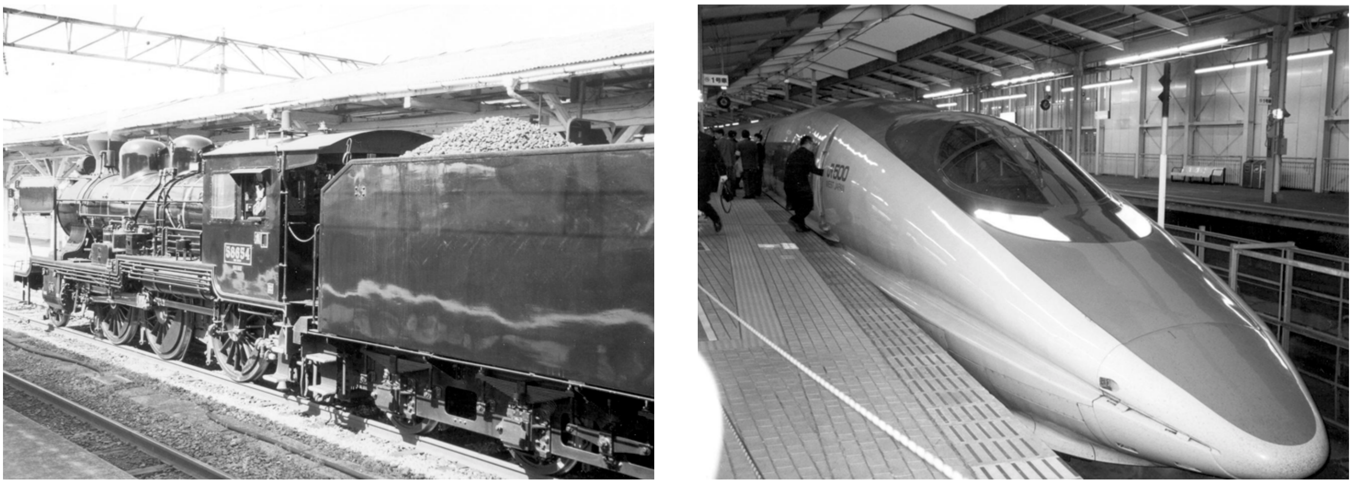
Introduction

The beginning of a new millennium is an appropriate time to review developments in railway technology, but the choice of time period for a review offers some interesting alternatives. Railway technology is old with roots back in the 19th century and more than 170 years of history since the opening of a developed form of passenger railway between Liverpool and Manchester. In principle, the technology today is the same as it was in the early days—the low friction arrangement of iron wheels on iron rails—but the implementation is vastly different. The past 50 years have seen a greater pace of change than any period since the pioneering days, so this period is perhaps a suitable and manageable period for review.

If I might start with a personal reminiscence—my own earliest memories (nearly, but not quite) 50 years ago, all involve the railway. My grandfather was a platelayer who belonged to a small gang tasked with looking after a few miles of railway that ran a short distance in front of the house where I grew up. I was often taken to share lunch with the men—perhaps fish and chips salted with scrapings from a huge pile of rock salt beside the small hut that was their base. There was ample coal for a fire that was always burning brightly and the talk was all railways. The track consisted of short lengths of rail supported on wooden sleepers held in place by wooden wedges driven between cast iron chairs and the web of the rail. The clickety-clack of the wheels passing over the rail joints was a much loved and characteristic feature of railway travel. My recollections of carriages are of their wooden construction, separate compartments without a corridor, bench seats that ran across the width of the carriage and heavy leather straps used to lower the windows in order to lean out to open the door catch.

And there were fogs. Dense fogs that reduced visibility to a couple of meters (6 ft in those days), thus rendering the oil lamp of the signals invisible to the engine drivers. I was allowed to assist, in practice that meant watch, as detonating charges were placed on the line. Enormous trains hauled by powerful steam locomotives hurtled out of the fog exploding the detonators by their passage and were thus advised of the signal aspect by the number of bangs. Even this small fragment of memory serves to remind me how much things have changed. Nearly all steam engines have now gone, track maintenance is no longer so labour intensive, signalling has been revolutionalized, dense fogs are no more (at least in England) and the line that I remember so well has long since been torn up and the land used for other purposes.

In order to give some order to the changes that have occurred, it is necessary to remind ourselves of some fundamentals of the railway. The principal characteristic, the now steel wheel on steel rail, has already been mentioned. The rail provides guidance, a stiff contact and low friction that allows large loads to be moved with low power requirements. The same properties mean that braking is relatively poor, so elaborate signalling arrangements are needed to give sufficient warning before a stop is required. Vehicles run on this track to form a 'system,' used here to mean an interdependence of the component parts of track, signals and vehicle. Although the glamorous part has always been the vehicle, we should not forget



The typical simple mechanical steam engine of 50 years ago has been replaced by the complex mechatronic train exemplified by a Series 500 Shinkansen. (Author) the critical role played by the track and the huge contribution to the expenses of running a railway eaten up by initial track building costs and subsequent maintenance. Once laid, the track is geographically inflexible, so that the shape of our railways (or system used in the sense of extent and location), is still largely determined by the routes laid many years ago back at the beginning of the railway age.

Comparison of systems now and 50 years ago

The world's railway systems now consist of about 1.3 million route-km, carrying about 2.2 trillion passenger-km and 10.3 trillion tonnes of freight. Perhaps surprisingly for those of us who have witnessed railway systems in decline, the total route-km of 50 years ago is approximately the same as the route-km today. Closures in the past 30 years have been balanced by building of new railways, both high-speed and freight routes. The many different circumstances in various regions and countries are summarized in Table 1, which needs a word of explanation because the data are subject to the vagaries of definition and inadequacy of collection mentioned in the quoted sources. However, the figures are sufficient to reveal the broad overall trends. The function of a railway is to move either or both passengers or freight, so productivity of a system is defined here as the sum of the passenger-km and freight-km divided by the route-km of the system. For each country, the upper and lower rows refer to data 50 years ago and the latest available figures, respectively. The final column is the ratio of productivity now compared with 50 years ago—values greater than unity representing greater productivity.

It is clear that some systems have grown remarkably in size, China being the prime example. On the other hand, the USA shows a more than halving of route. In productivity terms, all but one of the systems has increased. The huge increase in Brazil deserves special mention, being a result of the use of rail freight in developing the mineral-rich Mato Grosso. Closures in the USA have resulted in great freight productivity on the remaining routes. One third of freight in the USA moves by rail, but the small system of Ireland (not shown) carries more passengers than Amtrak. Draconian closures in the UK during the 1960s removed many little-used routes, but productivity increases have been modest due to lack of technological improvements. Of course, if further subdivisions are used, examples of very intensive use can be

Table 1 Comparison of Present Major Railways with 1950

	Route-km	Freight (million tone-km)	Passengers (million passenger-km)	Productivity	Ratio 1998/1950
Canada	69,167	149,000	4,532	2.22	
	69,677	304,233	1,341	4.39	1.98
Mexico	23,332	9,391	3,025	0.53	
	26,613	41,957	1,799	1.64	3.09
USA	360,137	864,000	51,161	2.54	
	170,200	1,979,835	19,449	11.75	4.62
Argentina	42,864	17,309	13,229	0.71	
	34,059	7,659	10,642	0.54	0.75
Brazil	36,681	8,066	10,267	0.50	
	26,962	428,873	1,539	15.96	31.94
France	41,300	38,900	26,400	1.58	
	31,939	48,136	55,311	3.24	2.05
Germany	49,819	58,200	48,840	2.15	
	40,826	68,490	60,514	3.16	1.47
Italy	21,550	10,400	23,578	1.58	
	16,003	21,720	49,700	4.46	2.83
UK	31,336	36,200	32,472	2.19	
	16,536	12,292	28,656	2.48	1.13
Russia/USSR	116,900	602,000	88,000	5.90	
	147,500	3,362,200	384,000	25.40	4.30
S Africa	20,175	23,411	n/a	1.16	
	25,555	95,591	9,675	4.12	3.55
China	22,200	39,406	21,236	2.73	
	54,616	1,287,420	354,261	30.06	11.00
Japan	27,401	33,823	118,000	5.54	
	27,404	24,747	395,278	15.33	2.77
India	54,845	44,163	67,065	2.03	
	62,725	277,567	357,013	10.12	4.99

Upper value 1950 data from International Historical Statistics, Mitchell, BR, Europe 3rd. Ed., 1992
Africa, Asia & Oceania, 2nd Ed., 1995, The Americas, 2nd Ed., 1993.
Lower value, for various recent years, from World Bank Railway Database, 1998
Productivity defined as (million tonne-km + million passenger- km)/route-km

found. JR East, for example, carries about 6 billion passengers a year on a network half the size of Britain's.

Table 2 amplifies this point with the same caveats regarding data accuracy. The uniqueness of Japanese passenger operations is well illustrated, but note that in the much less densely populated region of the northern island of Hokkaido, the usage figure falls to a much lower value that is typical of some regions of western Europe. Within the UK, the railways of Scotland are very little patronized. The commuter routes into London, exemplified by Connex South East figures, and the major East and West Coast main lines from London to Scotland are about 25 times less well used than similar routes in Japan.

These comparisons make the important point that although many commentators 50 years ago supposed that the railway had served its purpose and would decline, these pessimistic forecasts have not occurred. On the contrary, despite the explosive growth of road and air traffic over the last 50 years, the railways have at least held their own and increased their productivity in the functions they best serve. Given sufficient population density for passengers, these functions are commuting into cities and intercity travel up to distances of about 600 km. For freight, these functions are long-and short-distance haulage of heavy bulk cargo. The role of technology in assisting these improvements in productivity is worth further study.

An Old Railway Renewed

In 1950, most major railway systems were slowly recovering from the damage and heavy usage sustained during World War II. Although some notable speed records were achieved in the 1930s, during the immediate postwar years, overall average speeds for long distances by express rarely exceeded 100 km/h. Much attention was paid to longer-term strategies involving the choice of traction—should steam be replaced by diesel or electric?

Table 2 Comparison of Route Usage Intensity

	Route-km	Million passenger-km/year	Daily passenger density
Japan	27,404	395,278	39.5
France	24,122	61,573	7.0
Switzerland	2,843	12,386	11.9
UK	15,034	31,949	5.8
Japan, Tokaido Shinkansen	553	39,400	195.2
JR East (Tokyo region)	1,117	77,030	188.9
JR Hokkaido	2,500	4,540	5.0
Odakyu Electric Railway (private Toyko railway)	122	10,510	236.8
TRTA[1] (Tokyo subway)	172	15,864	253.4
UK, GNER[2] (East coast)	1,505	3,953	7.2
Virgin West Coast	1,164	3,901	8.1
Connex South Eastern	774	3,114	11.0
ScotRail	3,034	4,883	1.7

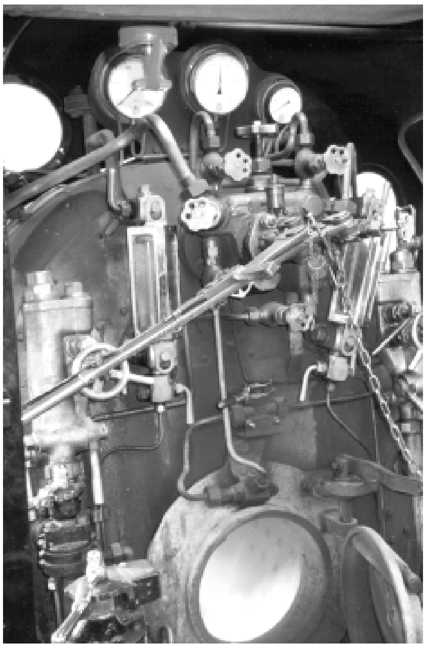
Daily passenger density defined as (1000 passenger-km/day)/route-km
Japan data from various company reports, financial year 1997—98
UK data from Shadow Strategic Rail Authority Annual Report 1999—2000
1) Teito Rapid Transit Authority
2) Great North Eastern Railway

Britain's plan for 1950s modernization

Taking Britain as a case study, by the time a modernization plan was prepared in 1954, the principal engineering feature was 'to produce a thoroughly modern system able fully to meet both current traffic requirements and those of the foreseeable future.' Other key engineering issues were:

- Improvements to track to achieve higher speeds over trunk routes
- Replacement of most existing mechanical signalling equipment by light signals using coloured lamps and power operated signal boxes; improved safety measures by extending automatic warning control to all main lines; and complete modernization of telecommunications
- Replacement of many existing passenger coaches by multiple-unit trains and introduction of locomotive-hauled trainsets incorporating new structural techniques and improved bodies, ensuring much higher standards of comfort and amenity
- Equipping most freight rolling stock with continuous brakes and improved buffers and drawgear; introduction of larger wagons particularly for bulk ores; and extensive modernization of wagon loading and unloading appliances
- Provision of new mechanized marshalling yards with automatic controlled wagon retarders involving heavy earth works and extensive track laying

The two features of this plan that had the most far-reaching consequences




The hard and dirty physical working conditions of the steam locomotive have been replaced by the calm, air-conditioned, computer controlled cab of the 500 Series. (Author)

were the replacement of steam, and the replacement of manual block working and semaphore signalling by multi-aspect coloured light signalling together with the great extension of areas brought under direct control of the new signal boxes. Without the latter, higher speeds at closer headways would have been impossible.

Replacement of steam traction

Like similar schemes in other countries, this British plan took a long time to implement and it was 11 years before the last of the 16,000 steam locomotives of 1954 were withdrawn and replaced by about 2900 main-line diesel locomotives and 4000 diesel multiple units. These figures themselves give a clear indication of the efficiencies delivered by the change in traction. Introduction of self-powered multiple units offered much greater flexibility of operation than a single power unit hauling coach stock both for commuter operations and for less busy services on rural branch lines. An indication of the heavier duties expected from the main-line locomotives, can be judged from the fact that although 2000 hp (1.5 MW) was sufficient to haul any express in 1954, 3300 hp (2.5 MW) units were eventually needed to handle the London Kings Cross to Edinburgh services. In Britain, electrification was surprisingly slow (Table 3). Although the ratio of electrified lines in Britain was small, most of what had been converted was south of London and based on the early 20th century third-rail 650–750 V DC system. In the postwar years, experiments mainly by the French, established the superiority of the 25 kV AC system. After considerable debate, this standard was adopted for future schemes in the UK and elsewhere.

Upgrading the West Coast main line

In the early 1960s, a major project to upgrade what is called the West Coast main line, from London Euston to Birmingham, Manchester, Liverpool and eventually, Glasgow, was undertaken. Apart from electrification and improved signalling, this involved relaying virtually the entire roadbed

Table 3 Electrified Route-km in 1949

	Electrified route-km	Percentage of route-km
Britain	1150	4
France	3820	9
Germany	2350	5
Japan	7340	27

with deeper and more substantial ballast, and relaying the track with reinforced concrete sleepers and continuously welded rails. At the time, this line was one of the fastest and busiest in Europe. The new electric trains could reach speeds of up to 100 mph (150 km/h) over level or easy up gradients, but the route was sinuous and contained many small-radius curves and some gradients as heavy as 1 in 75 (13 ‰), considerably reducing average overall speeds. The modernization was well received by the public and ridership increased sharply with new business attracted by the 'Sparks effect.' Although it was recognized that these improvements would be insufficient in the longer-term, construction of a new alignment was rejected on the grounds of cost and non-availability of land, particularly near towns. Interestingly, neither objection prevented a bludgeoning motorway building programme! It was finally decided that a new type of train would produce an adequate return. The result was the Advanced Passenger Train (APT), which was designed to tilt on curves and thus reduce or eliminate the unpleasant effects of centrifugal force on passengers. The power-to-weight ratio was to be reduced by using aircraft-type construction methods, thus pushing the maximum speed on conventional track up to 155 mph (250 km/h). In the event, although the prototype achieved some spectacular runs, it was dogged by teething problems, an over-ambitious combination of novel engineering features, and substantial under funding. Finally the project was dropped. However, some lessons were learned and incorporated in the more conventional High Speed Train (HST), which has been the backbone of the British cross-country and intercity fleet for 25 years. At sustained running speeds of up to 125 mph (200 km/h), it is still the fastest diesel train in the world.

A New Railway—The Shinkansen

Origins

In the early 1950s, the phrase 'Railway-Downfall Theory' was much used in Japan (and elsewhere). Just as horse carriages, canals and sailing ships had been superseded by trains and steamships early in the 19th century, it was supposed that the latter half of the 20th century would see the supremacy of automobiles and aeroplanes. As a result, the railway was thought to be on the road to decline and extinction. In Japan at this time, automobile production was gradually increasing, construction of motorways was about to start and civil aviation had been restarted. Many JNR personnel even subscribed to the Railway-Downfall Theory, but it was overcome by the vision of a small number of managers, central amongst whom were Hideo Shima (1901–98), JNR Vice President for Engineering and Shinji Sogo (1884–1981), the newly appointed JNR President.

At this time, the busiest route in Japan, the Tokaido main line linking Tokyo with Nagoya and Osaka was stretched to capacity and there was the question of how to support traffic on this key artery. Various alternatives were considered and the most obvious was addition of extra narrow-gauge (1067 mm) tracks either parallel to the existing tracks or on a new alignment. But this idea was found to be impracticable because of the congestion of new buildings along the route, the large number of level crossings (more than 1000) and the radii of existing curves preventing high-speed running. However, a completely new standard-gauge line would be free from crossings, would have gentle curves and, importantly, would be free from the constraints of older facilities and 'released from JNR's old habits.' In May 1957, a public lecture was given at the JNR Railway Technical Research Institute (RTRI) to commemorate JNR's 50th anniversary. The lecture title was 'Tokyo to Osaka in Three Hours—Can it be Done?' and was based on studies at RTRI. It proposed creating a completely new technology and standards for track, safety, trolley wire, etc., far from traditional railway concepts. It suggested that it was possible to cover the 550 km between Tokyo and Osaka in 3 hours by electric train at a maximum speed of 250 km/h. It is worth noting that boosting capacity rather than increasing speed, was the primary driver. Early plans included provision of freight trains, but these were soon excluded, thus contributing to a further decline in rail's share of freight in Japan, which is now very small (about 5% of tonne-km).

A commission under the Minister of Transport proposed building a new Tokaido line to standard gauge and the government accepted the plans in December 1958. The aim was to complete the project within the remarkably short time of 5 years, It required development of many new technologies and major civil engineering works, including driving the 7950-m Shin Tanna Tunnel to clear a major bottleneck at the Hakone mountains.

Some key technologies included use of 25 kV AC power to overcome the limitations of the 1500 V DC supply used on electrified sections of the existing narrow-gauge system, abolition of line-side signals and provision of all necessary in-cab signalling for the driver, adoption of a comprehensive system of Automatic Train Protection (called Automatic Train Stop or ATS in

Japan), use of distributed power along the train axles to reduce the heavy axle loads of locomotive-hauled trainsets, and use of new technologies for track running for considerable lengths on low reinforced-concrete viaducts.

Growth of Shinkansen

Passenger numbers on the Tokaido Shinkansen increased rapidly after its opening in 1964 and the 100 millionth passenger was recorded shortly after construction work began on the westward San'yo Shinkansen extension to Kobe and Okayama in March 1966. By March 1975, it was possible to travel the 1069 km from Tokyo to Hakata in Kyushu in 6 hours and 40 minutes. By 1982, the Tohoku and Joetsu shinkansen started running to the north east and north of Tokyo, respectively. In 1998, a branch of the Joetsu Shinkansen to Nagano was completed to service the Nagano 1998 Winter Olympic Games and further extensions are currently in planning. In addition to extensions of the shinkansen lines, several new generations of shinkansen trains have been introduced, the fastest of which runs at scheduled speeds of 300 km/h on the San'yo Shinkansen between Osaka and Hakata.

Clearly, the shinkansen has answered the challenge from domestic airlines to become the dominant mode for journeys of up to 600 to 700 km. Its revolutionary nature is illustrated by the travel times shown in Table 4.

These figures refer to a journey along half the length of Japan, from the capital to Kyushu, the southern island, some 1000 km distant. In the last 70 years, what was nearly a 24-hour single journey has been reduced to less than 5 hours, making a 1-day return journey for a business meeting a practical proposition.

Catalyst for the new age of the train

The importance of the shinkansen to railways is immense and extends far beyond the boundaries of Japan. At the time of its opening in 1964, western counties were developing conventional lines and greeted the practicalities of building a completely new alignment with considerable scepticism. However, the immediate commercial success of the shinkansen caused a rapid reappraisal and high-speed trains were soon running in France (TGV) and Germany (ICE). Spain, Sweden, and Italy followed later with Korea and soon Taiwan becoming the latest members of the high-speed club. Where new lines have not been built, speeds have still increased greatly because of the way forward shown by the remarkable railway engineering from Japan. The success of the shinkansen not only prompted introduction of high-speed trains elsewhere, but was a beacon of optimism for railways generally, and did much to disperse widely held pessimistic views on the future of railways. As a footnote, I might mention that a retired Series 0 shinkansen driving car with the original iconic rounded bullet nose has been donated by JR West to the National Railway Museum in York, England, where it will be displayed near Stephenson's *Rocket* and the world speed record steam engine *Mallard*. After writing this article, I shall be visiting Yokohama Port to witness the departure of this Bullet Train from Japan on its long journey to it wholly appropriate resting place beside the catalyst of the first age of railways.

Dependence of Railways on External Influences

Opportunities from imported technologies

In general, railways have been rather poor at developing their own technologies in a strategic manner, but have been content to react to developments outside the industry by taking advantage of available opportunities. This situation differs markedly from the larger and more technologically advanced aircraft industry and the hugely larger automobile industry, both of which have always had considerable internal research efforts.

In the days of steam traction 50 years ago, it is extremely unlikely that any commentator could have predicted the incredible rise and availability of computing power that has occurred during the last two decades. In common

Table 4 Changes in Travel Times between Tokyo and Hakata

	Train	Tokyo depart	Hakata arrive	Transit time	Scheduled speed (km/h)
1930	*Fuji*	13:00	11:23	22 h 23 min	54.7
1960	*Asakaze*	18:30	11:55	17 h 25 min	69.0
1964	*Hikari 5*	21:30	13:30	13 h 30 min	85.7
	Tsubame				
1975	*Hikari 1*	07:00	13:56	6 h 56 min	154.2
2000	*Nozomi 1*	06:00	10:49	4 h 49 min	222.0

with many other industries, railways are now dominated by computing over a wide range of activities from signalling and control to scheduling, ticket sales, real-time information and marketing, to say nothing of the mechatronic train, which has replaced the essentially mechanical motive power of 50 years ago. Solid state and power electronics have improved the spatial densities of electric motors to permit more compact distributed-traction units, which in turn provide numerous advantages in train operations.

The availability of ever-increasing possibilities for communications at sharply decreasing cost has been a significant feature of the last two decades. The portable telephone, e-mail and the Global Positioning Satellite (GPS) are now so much a part of daily life for most of us that it is difficult to imagine they are recent introductions. The opportunities already taken and future possibilities for railways are enormous. A good example is the use of GPS technology to track freight consignments on routes across the USA. There are other examples, such as the use of GPS to control the position of trains in remote regions—a technique that is much cheaper than conventional signalling.

New materials have enhanced and extended the performance of equipment. New composites and new production technologies for older materials, such as long aluminium extrusions enable lightweight, but safe rolling stock to be manufactured efficiently. The wooden carriages of my youth have been replaced by coaches of steel, aluminium, stainless and composites. They are lighter, more easily maintained, are air-conditioned and have many other passenger amenities that were undreamed of 50 years ago. Their suspensions and improved track quality give greatly enhanced levels of ride comfort and much quieter internal environments.

Instrumentation and sensors, allied to diagnostic technologies, are beginning to allow more efficient, timely and productive maintenance, a trend that will surely increase.

In civil engineering, new projects such as the Seikan Tunnel (linking Honshu and Hokkaido in Japan) and the Channel Tunnel (linking France and England), have been completed on the back of much improved construction technologies. Likewise, new bridges, such as the Øresund Fixed link between Denmark and Sweden, dwarf the bridge projects of the pioneering years. And new underground urban railways can now be constructed with minimal disruption to surface activities.

Internal research

Perhaps the only major areas where railways have developed their own technologies can be found at the wheel–rail interface. The problem of lateral instability in the running of a railway wheelset was intensively but independently studied by teams at national railway research centres in the UK and Japan. The knowledge gained has allowed safe running at speeds beyond 300 km/h without damage caused by hunting. The severity of conditions at the wheel–rail contact point, which is typically the area of a 5-pence piece or ¥10 coin, have led to extensive studies on the balance between wear and fatigue at this critical interface. As rails have been head-hardened to withstand wear deterioration and prolong life, fatigue cracks have become more prevalent with their initiation accelerated by a combination of higher axle loads, higher speeds and more severe traction/braking conditions. In recent months, due to a lack of management of the rail running surface under conditions favouring crack initiation, a major high-speed derailment at Hatfield resulted in four deaths and subjected the UK travelling public to the worst network disruption in the nation's history.

However, the trend in recent years within most parts of the British railway industry has been a decrease in railway-centred research. The reason is not that there are no fundamental problems to solve, but rather arises out of a change of ownership in the industry.

Privatization and separation of infrastructure

Fifty years ago, most of the world's railways were in government ownership. The main reasons were the huge scale of the activity and the historic strategic importance of railways in the affairs of nations. For both military and civilian economic reasons, most governments thought it necessary to keep railways under their direct control. The major disadvantages of this system were later perceived to be insularity, complacency and poor service provision from employees, overmanning, and lack of investment as governments sought to prioritise budget choices between education, health care, defence and the desire to reduce taxation. In the 1980s, the seeds of the benefits of privatization were planted in Britain by successive Thatcher governments, and rapidly propagated throughout the world. The EU required member states to separate the accounting for railway infrastructure from operating costs in an effort to pave the way for entry by third-party operators. Although not specifically required, many administrations privatized their railways whilst simultaneously separating infrastructure and operations. This is not the place to debate the wisdom or otherwise of these moves, but it is obvious to many that privatization has been more

successful where vertical integration of the railway has been retained (Japan) rather than where separation of ownership has occurred (UK).
The important effect of privatization on technology has been the decline of integrated research. Japan has retained a national effort financed partly by a levy on ticket sales with the result that RTRI in Tokyo is possibly the leading centre in the world for advanced railway research. In most other cases, it has been assumed that responsibility for research will filter down to the external provider of equipment or services, and major efforts cutting across the range of technologies needed to run the railway have declined. What were previously national laboratories have been switched to specific problem solving roles, which leads to important questions about their distance from cutting-edge technology and opportunities for intellectual renewal in the future.

The Next Fifty Years

Key issues

As we have seen, although the demise of railways was confidently predicted 50 years ago, in fact the last half century has seen a strengthening of conventional operations and the birth of the dedicated high-speed railway. Of course, it is difficult and unwise to predict what the next 50 years will bring, but it is clear that the explosive growth of transport that has occurred over the last 50 years is likely to continue because it is inexorably linked to economic growth and, despite current discussion about the need for sustainability, growth is the only economic model that we can comfortably manage.
But our increased prosperity has been bought at a high price. The depletion of resources coupled with the environmental deterioration brought about by our exponentially increasing economic activity are now issues of global concern. Therefore, as I write, it is very depressing to hear that US President George W. Bush is talking about rejecting the Kyoto Protocol on Climate Change. This critical issue for future generations needs inspired leadership now rather than narrow short-term economic self-interest. In transport, factors such as increasing road congestion, shortage of air-traffic slots for short-haul flights and, above all, local, regional and global pollution caused by fossil-fuel based transportation systems, are all acting as incentives to move to more environmentally friendly and efficient transport modes, particularly railways. But railways have no room to be complacent about the opportunities presented by a rapidly changing world. These negative and passive drivers favouring railways must be complemented by active and positive attractions, such as improved service, reliability and capacity. Smooth and trouble-free links with other modes must be encouraged as must even better information and flexible ticketing systems.
It must be recognized that the weakness of our current railways is the very high cost of infrastructure. The huge expense of building new lines mitigates against their construction so we are often left with the unsatisfactory alternative of struggling to improve routes whose geography was determined by historic patterns of population distribution and travel requirements. The infrastructure is also very expensive to maintain, particularly to the high standards required by higher-speed traffic. Thus great technical efforts are needed to reduce the labour intensity of both building and subsequent maintenance. With very few exceptions in extremely high-density population regions, it is difficult to find examples of railways that can pay their infrastructure costs from the fare box. Some hard and far-reaching policy decisions must be taken. On one hand, this may mean that users will have to pay the full cost. But if railways are to compete on a level playing field with other transport modes, full-cost accounting must also be applied to competitors with all external costs such as road accidents and air pollution, etc., properly accounted for. On the other hand, it is more likely that infrastructure costs will have to be paid by greater contributions from national budgets.

New technologies

We have seen that technical progress of railways has been incremental, with the greatest benefits coming from the replacement of steam traction by diesel and, above all, by electric power. Environmentally, the greatest benefits will come from renewable electricity sources. Countries like Switzerland, which have harnessed abundant hydro-power, have run nearly 100% electrified railways for many years. It could, and probably should, be argued that nuclear power is the only quasi-renewable large-scale energy source. But in many countries, like the USA, Germany and the UK, current policy is to reduce the proportion of power generated by nuclear stations and there are no plans for new builds. Perhaps, the unprecedented power shortages now being experienced in California will serve to focus thinking in this vital area. Alternative solar and wind resources are too small and inappropriate for large regions of the earth, but tidal power shows sufficient scale and availability to be encouraging. It is possible that fuel cells offer a way forward for transport applications but research needs to be conducted with greater urgency.

In the past 50 years, best average speeds have increased remarkably from less than 100 km/h to more than 300 km/h. Despite the French rail speed world record in excess of 500 km/h, it is difficult to see normal operational speeds for the steel wheel on the steel rail system increasing by much more. The Achilles heel is the infrastructure, track damage, current collection wire, and sharply increased power requirements with increasing speed. Furthermore, the limits on adhesion, noise and vibration, and dynamic running stability of vehicles are rapidly being reached.

What of other forms of traction? The train has already achieved nearly half the cruising speed of a commercial plane, so what land-based method might fill the gap in the 400 to 600 km/h region? The Maglev system in Japan has demonstrated its capabilities at 500 km/h running but the infrastructure costs are currently estimated to be a least three or four times higher than conventional track, so the limitations to Maglev use may be economic rather than technical. It is possible that other systems may be developed using rails for guidance rather than power transfer, but it is impossible to predict such developments.

Ending on a personal note, I am very unlikely to be around to see what forms our railways will take in 50 years time. But it is reasonable to assume that they will continue in a developed form of their current state for at least the next two or three decades. I expect them to be playing a valuable role in efficient and comfortable transport of people into our ever-growing cities 600- or 700-km apart and in the carriage of goods over substantially longer distances.

The future technologies that will sustain our railways must be harnessed to new ways of thinking about the needs of passengers and their desire to accomplish a seamless door-to-door journey. Will the future bring about a further progression of our description of passengers as 'customers' to 'guests'? ■

Maglev—the technology has already achieved a world record of 552 km/h in Japan, but will the infrastructure prove too expensive? (JR Central)

Further Reading

Many of the topics in this article have been discussed at greater length in previous issues of *JRTR*.

The shinkansen and its wider influence was the subject of *30 Years of High-Speed Railways* in *JRTR* No. 3. Various methods of privatization were introduced in *Restructuring Railways* in No. 2 and again in No. 8.

Environmental topics were treated in issues No. 17 and No. 18.

It was not my intention to discuss technical details of railway technology in this article, which is covered by the excellent series of 13 *Railway Technology Today* articles starting in *JRTR* No. 14.

Roderick A. Smith

Professor Smith is Head of the Department of Mechanical Engineering at Imperial College, London. He was Royal Academy of Engineering Research Professor of Advanced Railway Engineering and Chairman of the Advanced Railway Research Centre from 1995 to 2000. He has published eight books and more than 250 papers including several previous articles in *JRTR.*