Future of High-Speed Railways

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1. Significance and Merits/ Demerits of Shinkansen

The technical content of the shinkansen was first made public at a lecture held by the Railway Technical Research Institute (RTRI) of JNR celebrating the 50th anniversary of its foundation in 1957 when Japan still had yet to recover completely from the defeat of World War II. In the same year, the Odakyu Electric Railway and RTRI jointly developed the first real super express car in Japan establishing a new Japanese record of 145 km/h in a test run executed by JNR.

The successful development of the shinkansen owes most to two great men: Mr Shinji Sogo, the President of JNR, who believed in the RTRI group and showed strong leadership to promote its development under difficult circumstances; and Mr Hideo Shima, the Chief Engineer, who coordinated technical affairs under the leadership of Mr Sogo.

From the technical viewpoint, the shinkansen owes its success to selection of a completely different gauge from the narrow-gauge (1067 mm) conventional lines which are unsuitable for high-speed running, as well as to design concepts combining proven techniques as far as possible.

The technical and business success of the shinkansen came as a great shock to the conservative railway industries in Europe and America who had long believed that the maximum working speed of railways was about 160 km/h. It also led to the revival of European railways. High-speed passenger trains were even tried in the USA, where inter-city railway passenger transport was already in decline and where railways were no more than a freight transport business.

Five years after the shinkansen commissioning, a plan was developed in 1969 to operate a super express non-stop between New York and Washington in 2 hours and 30 minutes. However, the plan failed due to technical problems. It was later modified to introduce Swedish technology, and today, the trains connect New York with Washington in about 2 hours and 50 minutes.

On the other hand, after the Tokaido Shinkansen, high-speed railways in Japan meant no more than the Tokaido Shinkansen, making real technical development—developing and applying different techniques in different conditions—difficult. Concretely speaking, almost the same system as the Tokaido Shinkansen was used for the Tohoku Shinkansen despite their great differences in the magnitude and seasonal variation of demand. This promulgated their characteristically-poor current collection by multiple pantographs for more than 20 years. In addition, there were almost no speed increases in areas without shinkansen lines.

The Tokaido Shinkansen was constructed on a very favourable route with the largest and most stable demand in the world. Therefore, despite the huge investment, it soon became profitable as long it offered high-quality service. However, constructing shinkansens does not pay elsewhere unless the construction costs can be cut, and improvement of conventional lines is usually more efficient than constructing a new line. It is regrettable that the great success of the Tokaido Shinkansen nipped diversified technical development in the bud.

2. Quick Response in Europe

European railways, which had a long experience of higher-speed operation at up to 160 km/h, responded quickly to the shinkansen. France and Germany quickly developed locomotives with high power and excellent performance as well as new passenger cars with rail brakes, new signalling systems, etc. Services soon started at 200 km/h on favourable lines. Germany planned to reach service speeds of 200 km/h as early as 1965, but high-speed operation was forcibly suspended due to track deterioration. However, as a result of the 1966 French success, achieving 200 km/h with a train hauled by an electric

■ British Rail HST at Paddington Station (T.SUGA)

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locomotive was no longer such a milestone success.

On one hand, 200 km/h operation was achieved on conventional lines by extending conventional technology, and on the other hand further speed increases were tried by developing new technology and constructing new lines. The success of the shinkansen apparently started revitalisation of railways worldwide.

3. Shinkansen Drawbacks Answered in Europe

The British HST (High Speed Train) was the first to achieve high-speed operation. Trunk lines in Britain suit high-speed running because the curves are gentle and there are almost no crossings. The British planned to increase the speed of the HST using the APT (Advanced Passenger Train) without constructing new lines. The HST reached 201 km/h on non-electrified sections, while the APT reached 250 km/h on electrified sections. HST operation started successfully in 1976.

The first commercial HST, or 253 Series, was made up of two lightweight (67 tonne), high-power (1680 kW) diesel electric motive power units with a small baggage room and a small conductor room as well as 7 trailers, or passenger cars, between them. Current knowledge of high-speed railcars suggested that with this formation, the train should not have been able to accelerate when the adhesion was poor, and the braking distance should have been poor. But, in practice, the train showed better acceleration/deceleration performance than Japanese shinkansen and ran stably at high speeds. Japan could have learned much from the HST including its high-speed adhesion performance, and reduced running resistance achieved by covering under-floor equipment, etc.

■ French TGV Sud-Est at Paris (T.SUGA)

The TGV (Train à Grande Vitesse) was developed by France in 1981 as a vehicle dedicated to new high-speed lines. It resembles the Japanese shinkansen in purpose, but differs greatly in design philosophy. The differences are attributable to overcoming the disadvantages of the shinkansen. Namely, the TGV was completed by learning the lessons of the shinkansen. Table 1 shows the main differences. When France worked out these solutions in 1981, it was Japan's turn to learn from the TGV, but JNR did not evaluate the TGV soon enough or correctly. Since then, we have learned many things from the TGV and have at last succeeded in improving the notorious current collection system.

4. Unfortunate JNR Era

Looking back over 30 years of high-speed railways in Japan, the unfortunate JNR era cannot be forgotten. While the South-East TGV line was under construction in France, the Tohoku and Joetsu Shinkansen were under construction in Japan. However, it is difficult to say that 20 years of experience of the Tokaido Shinkansen was reflected in any technical or functional improvements. Neither were the economics of these lines thoroughly evaluated considering the comparatively small demand. In fact, their construction costs were too large, compared to the functional improvements. This is attributable to JNR's critical situation regarding labor-management relations and finance. This situation was reflected in the technical field, making it impossible to develop new technology.

When the JNR division and privatisation was finalised, the situation was gradually resolved, and the stagnating railway service and technology began showing rapid improvement. New speed records and new rolling stock are now being developed each year.

5. Different Japanese and European Styles

Even now, the technology and service differ greatly between Japan and Europe. It is useful to compare these differences, even if the conclusion confirms that Japanese style matches Japan, and European style matches Europe.

Re-recognition of Regenerative Braking and Distributed Traction

For comparatively long trains using DC motors, concentrated traction is probably more economical than distributed traction, based on the car construction and maintenance costs. However, in Japan, because of the quality of couplers and shock absorbers and because the push-pull system is uncommon, most passenger trains including shinkansen have distributed traction. Shinkansen used fully-motorised axles as a matter of course in the early stage, because of insufficient knowledge of adhesion limits. However, when the HST and other new trains showed that fully-motorised axles were unnecessary, concentrated traction slowly progressed as long as floor space was not sacrificed. The Series 100 shinkansen manufactured in 1985 has 12 motor cars and 4 trailer cars (12M4T). Two or four trailer cars are double-decker to increase seating capacity. A feature of the Series 100 trailer car is its brakes; an eddy-current disc brake activated by the motor current of the adjacent M car is used to lower the maintenance costs.

The Series 300 was developed with the same philosophy in a 10M6T formation. However, while the weight of the motor and driving gear was greatly reduced, the weight of the eddy-current disc brake could not be reduced as much, resulting in heavier trailer cars than motor cars for non-suspended and total mass.

Since AC motors require hardly any maintenance, fully-motorised axles should have been used for the Series 300 . As a result of learning this lesson, the Series 500 had fully-motorised ax-

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Table 1 TGV Improvements Based on Shinkansen Drawbacks and Influence on Japanese Railway

Drawbacks of shinkansen recognised by France	Causes from French standpoint	French solutions	Current state in Japan
Frequent overhead system breakdown	Excessive pantographs	Current collection by one pantograph on high-speed running sections	No. of pantographs changed from 8 to 3 for 16-car trains
Improper current collection			Nozomi has three pantographs, but only two are used.
Radio interference			The number of pantographs will be reduced to two in the near future.
Delayed recovery from accident	Double-track operation with fixed running direction	Parallel single tracks	Not yet adopted. To be applied to Chuo Shinkansen.
Securing transport capacity	Blind ATC	Predictive ATP	ATC improvement under discussion
Riding comfort			
Energy characteristics			
Poor ability to adjust to transport capacity	Fixed formation	Coupling of two formations	Different train formations used for Tohoku, Joetsu and Sanyo Shinkansens
	Fixed pattern diagram	Section train	Section train introduced to Tohoku Shinkansen
	Fixed fare system	Variable fare system	Slightly different fare system introduced for busy/slack seasons
Utilisation of transport capacity	Fixed reserved + unreserved seats	Reservation + overbooking	Not yet investigated
Inconvenient transfer	Through operation with conventional lines impossible	Basically through operation with conventional lines	Yamagata Shinkansen through operation introduced, but other resultant problems yet to be solved
Excessive construction cost	Gentle grade (maximum 1.5%)	Sharp grade (3.5%)	3% grade used for Hokuriku Shinkansen
	Too many tunnels	No tunnels	Even in France, some sections require tunnels. Various construction methods are used based on the soil.
	Too many bridges	Basically banking	
	Concrete-slab track	Gravel track	Same as above
	Distributed traction	Centralised traction	Distributed traction improved
	New lines constructed in heart of metropolis	Extension of routes into conventional lines	Impossible in Japan
	Heavy catenary	Light catenary	May be improved in future construction
Excessive maintenance cost	Distributed traction	Centralised traction	Distributed traction improved
		Articulated car reducing number of bogies	Articulated and bogie systems compared by STAR 21
Poor ride comfort in passenger cars	Distributed traction	Centralised traction	Distributed traction to be improved but not yet completed
	Bogies under passenger car	Articulated car	Articulated and bogie systems being compared in STAR 21

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les with the motor mounted on each axle but centralised power supplies. This system, which centralises power units if floor space permits but distributes traction motors, has the advantage that all floor space can be used as passenger room. High-speed operation is facilitated because the total mass per effective floor area is small, the maximum axle load is small, and mechanical braking is not usually used. When regenerative brake equipment is used for service braking, the heavy braking rheostat—a large onboard source of heat—becomes unnecessary, greatly increasing safety.

Fully-motorised axles are more advantageous for AC driven high-speed railcars and will prevail in the future.

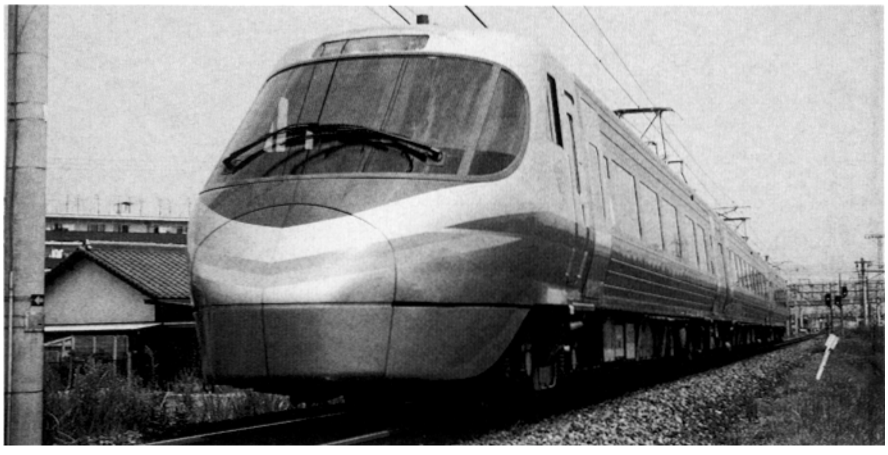
Electrically-Connected Dual Pantograph

Comparison between the TGV current collector and the Series 0 shinkansen, which uses 8 sets of pantographs distributed over the 16-car formation and generates much sparking, shows the superiority of the TGV. To increase the speed of the Series 200 shinkansen which has 6 sets of pantographs along the 12-car formation, the pantographs were connected by bus to investigate the effect on the current collection. It was concluded that two comparatively-separate pantographs are best, except for those at the ends of the formation, because even if one pantograph bounces, current collection is continued by the other pantograph. Also the bouncing pantograph does not generate much sparking. The Series 200 and 300 shinkansen operating up to 275 km/h have three sets of pantographs, but only 2 sets are used. The number of pantographs will soon be reduced to two. This method of current collection seems superior to the TGV electrically-connected one-pantograph system and the ICE independent two-pantograph system.

Japanese Advantages in Car Body Tilting Control

Although many countries have been trying to develop effective car body tilting control systems, few have succeeded in improving riding comfort. So far, only Japan, Italy and Sweden have solved the problem. I have compared these three methods on commercial trains (JR Shikoku Series 2000 DMU railcar and Series 8000 EMU railcar and JR Hokkaido Series 281 DMU railcar, FS ETR450 and DB VT610 for the Italian method, and X2000 for the Swedish method). All have no problem when passengers are seated, but there are some problems when they walk along corridors.

Since riding comfort differs greatly with track conditions and running speed, it is difficult to determine which method is superior. The Japanese method is based on a natural pendulum. The problems due to time lag in the pendulum motion on short curves have been solved by "feed-forward" control of the time lag calculated from curvature data stored in an onboard computer, based on train speed and current position determined by track detectors. This makes passengers feel that the train is running on a gentle curve and offers a comparatively good ride even under bad track conditions. From the viewpoint of adaptability to varying track conditions, the Japanese method is good. There are other possible advantages too such as automatic collection of data for track maintenance.



■ JR Shikoku Series 8000 EMU (JR Shikoku)

■ JR Hokkaido Series 281 DMU (JR Hokkaido)

Actual Adhesion Limit

High-speed running of the TGV-A with a centralised power plant (4M11T in bogie units), including operation in rain, showed that the speed limit of fully-motorised axles is high enough (approximately 460 km/h). This means that adhesion itself does not limit the commercial speed of wheel-rail railways. But this does not mean that an adhesion railway system running at 460 km/h will be practical. Considering the weight and size of current electrical equipment, such trains would be no more than locomotives, offering hardly any passenger space. In addition, there are many other problems other than adhesion to solve, such as noise. Therefore, it is unfair to insist from the adhesion viewpoint that development of new super-speed railways is useless.

High-Speed Running Test

At high speeds, aerodynamic drag dominates running resistance. The resistance is proportional to the square of the speed, while power is proportional to the cube of speed. From this point of view, it is unnecessary to establish a speed record higher than 500 km/h in the high-speed running test to achieve a maximum service speed of approximately 350 km/h. Therefore, although the speed record of 515.3 km/h established by the TGV is a great record, it is not indispensable to achieving commercial railway speeds of approximately 350 km/h.

For practicability, a speed 10% to 20% higher than the maximum service speed is sufficient. It is more important to perform sufficient running tests under various conditions than to aim just at higher speed.

Because of the distributed traction,

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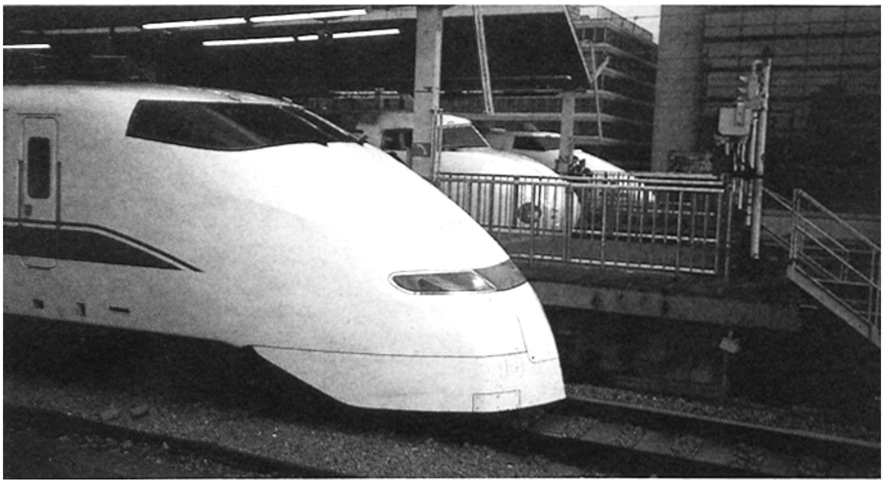

■ JR Central Series 300 Nozomi at Tokyo Station (T. SUGA)

unlike the TGV, the Japanese shinkansen cannot increase the power/weight ratio by removing intermediate cars. Test cars have been designed to achieve the real test speed, or about 1.2 times the maximum service speed, by replacing trailing bogies with motorised bogies to increase power (STAR 21 of JR East) or concentrating the traction power of four cars into three cars (WIN 350 of JR West).

Is MAGLEV Development Useless?

It is unreasonable to say that MAGLEV is useless based on the TGV 515.3-km/h record, which was achieved on a down grade with a dry track.

Introduction of new high-speed railways is opposed from various viewpoints, including noise, vibration, energy saving, efficient land use and safety. Selection of wheel-rail or MAGLEV systems is related to all these items. Both systems should be evaluated and the superior one should be selected. There is an opinion that high-speed surface transport is not necessary, because there are strong competitors like airlines. However, if it is possible to develop a new system that is superior to aircraft in terms of energy saving, efficient land use and safety, naturally, it should be promoted. The most important problem in Japan concerning construction of high-speed railways is noise. In this respect, MAGLEV has advantages because the car body is very light and the traction motors are installed on the ground, so no noise is emitted by current collection.

However, MAGLEV railways require many new developments and are not so advantageous at low speeds. Therefore, MAGLEV is less attractive for shorter development times, or lower target speeds. If it is necessary to develop a new railway system comparable to shinkansen or TGV quickly, MAGLEV will not be selected. However, the size of present electrical equipment makes it difficult for wheel-rail type railways to secure sufficient passenger space. For these reasons, MAGLEV is attractive at 450 km/h or higher speeds. If such a system can achieve greater energy saving, more efficient resource utilisation and higher safety than aircraft, it will be worth developing.

5. How Should Railways Improve Transportation?

Further Speed Increases

Speed is the most important factor in the transport competition. However, speed does not mean the maximum speed but the total trip time including access time and waiting time. Although speed has universal importance, the enthusiasm of the transportation industry and society for speed increases changes with time.

Of course, at some times it may be difficult to invest large amounts of money just to shorten the travel time slightly. However, even in recessions, speed increases can be promoted from the software viewpoint, for example, by re-examining stops, lines, and connections, etc. It is always important to keep speed increases in mind.

Safety and Environmental Friendliness

Typical transport modes competing with high-speed railway are aircraft and cars. Although these three modes of transport should each develop in their own fields to satisfy people's diverse needs, more passengers should be attracted to high-speed railways, because railway has a decisive advantage in terms of safety and environmental friendliness. Railway personnel should more actively appeal this point to government, companies and individuals. And railway staff should more actively tackle correction of systems or organisations obstructing development

Change from National to International Railway Technology

Although railway engineers in each nation share common bonds, internal cooperation is still insufficient. To make railways more attractive and to meet social needs such as environmental conservation, safety and energy saving, we must promote information exchange and cooperation.

The change from JNR to JR in Japan is one step typified by publication of this magazine. However, compared with Europe, the attitude in Japan towards exchange and cooperation is still insufficient.

Readers must cooperate actively by participating in the debate in this magazine. ■

Satoru Sone

Dr Sone was born in 1939 in Tokyo. He has long been interested in railways and graduated from university in electrical engineering because it seemed to have a great influence on new railway technologies. He has been a professor at the University of Tokyo since 1984, engaging in the study of transport system engineering and power electronics. He plays a positive role in the government-university-industry debate on transport policy.

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