Aiming at Higher Speeds for Shinkansen

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In this article, I would like to explain our strategy for increasing the speed of shinkansen in Japan. Then, I will discuss how our company has been tackling speed increases. Lastly, I will also give some details about future problems with increasing speed and the current status of our R&D.

What is JR East's current shinkansen network like? The network in 1987 was composed of the Tohoku and Joetsu shinkansen lines with a total track length of about 840 km. Subsequently, the network has been extended by the addition of the Yamagata and Akita mini-shinkansen followed by the Nagano Shinkansen opened just in time for the Nagano Winter Olympics in 1998. More recently, the extension of the Tohoku Shinkansen from Morioka to Hachinohe was opened on 1 December 2002. These new lines have extended the network length to about 1330 km in five directions (Fig. 1). Future plans include extending the Tohoku Shinkansen to Shin Aomori and the Nagano Shinkansen to Toyama. The shinkansen tracks from Tokyo to Shin Aomori will cover a distance of some 670 km and it seems likely that there will be future extensions.

Figure 2 shows the growth of shinkansen passenger volumes since the JNR privatization in 1987. At the formation of JR East, the shinkansen were carrying about 12 billion passenger-km. Today, that figure has risen to 18 billion passenger-km, an increase of about 46%. In fiscal 2001, the total revenues from JR East's shinkansen operations were about ¥460 billion or a massive 30% of JR East's total operations revenue.

Next, I would like to touch upon the conditions of high-speed railways around the world. Figure 3 shows that Europe has some 3200 km of high-speed railways with performance equivalent to that of Japanese shinkansen. In Germany, the new ICE3 services operating between

Figure 1 JR East Shinkansen Network

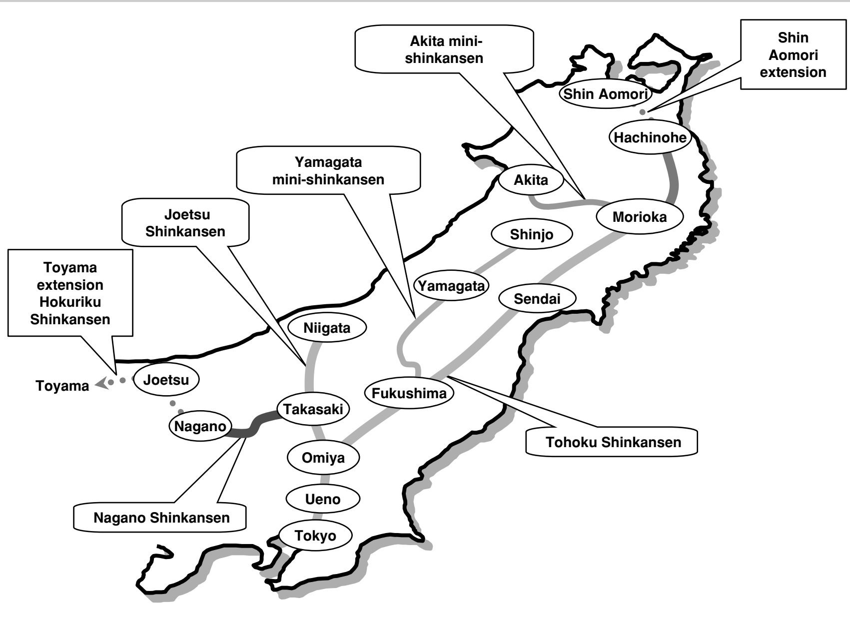


Figure 2 JR East Shinkansen Passenger Volumes

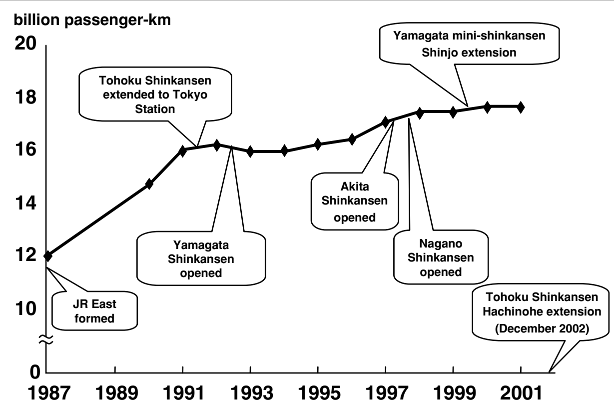


Figure 3 European High-speed Railway Lines

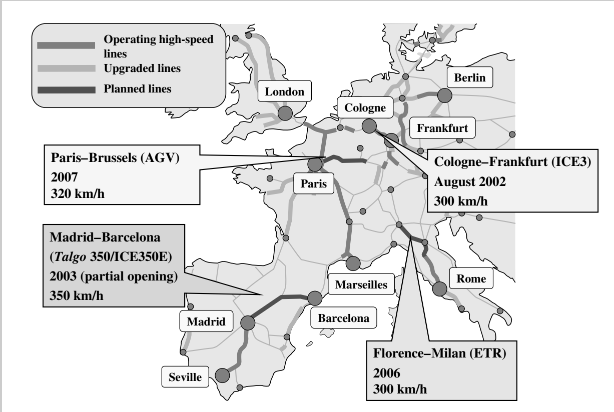
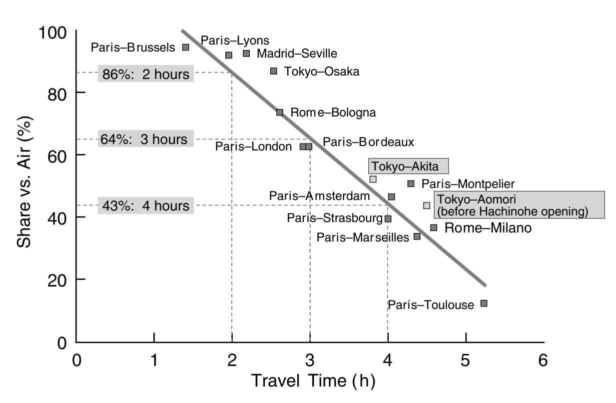
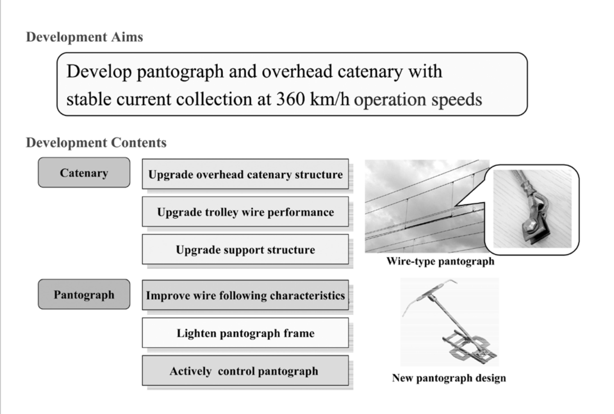


Figure 4 Journey Time and Modal Share



Source: UIRC HSR2000 Meeting

Figure 5 Improved Current Collection Technologies



Cologne and Frankfurt are reaching speeds in excess of 300 km/h. Other European countries, including Italy, France, and Spain have plans to open new high-speed lines. In particular, France is planning to start commercial operations eastbound from Paris and reaching Strasbourg by 2007. They are aiming to develop the next-generation TGV to be known as the AGV using new rolling stock with distributed traction like the shinkansen. In another development, Spain is planning the start of partial *Talgo* and ICE operations from Madrid to Barcelona at 350 km/h.

Next, I want to touch upon our targeted speed increases. Figure 4 shows the relationship between travel time and market share using data presented to UIC in 2000. The horizontal x-axis shows the journey time by high-speed rail and the vertical axis shows the market share of rail compared to air. For example, the high-speed TGV between Paris and Lyons opened in 1981 maintains a 90% share for a travel time of less than 2 hours. However, at the 3-hour travel time, such as a trip between Paris and London on the *Eurostar* through the Channel Tunnel, the market share drops to 64%. For longer journeys, such as the 4-hour trip between Paris and Marseilles, rail's market share falls even further to something around 40%. However, after the opening of the TGV Méditerranée line in June 2001 and the introduction of new rolling stock cutting the journey time to Marseilles to about 3 hours, the market share has risen to above 60%, indicating that projects to build new fast lines can have a major impact on railway business.

After the opening of the Tohoku extension from Morioka to Hachinohe, which reduced the travel time from 3 hours 33 minutes to 2 hours 56 minutes, we were expecting a rise in market share but the domestic airlines responded with price cuts, leading to hot competition between air and rail over this sector. Similar problems have occurred in Europe but European rail operators are making strenuous attempts to reduce travel times by aiming at increased maximum operations speeds of 350 km/h. In the future, we can expect severe competition with the airline industry and one solution is R&D into operations at maximum speeds of 360 km/h. However, increasing operations speeds has negative side effects such as increased running noise from overhead equipment like pantographs. This will require other R&D into new noise-reduction technologies, such as pantograph covers, which are now being incorporated into designs for low-noise shinkansen train sets.

The rest of this article deals with the problems of increasing shinkansen speeds and some of our R&D results.

So how can we achieve speed increases up to 360 km/h; will we be able to achieve our targets; what concrete developments are needed; and will we be able to obtain the cooperation of related bodies while performing the necessary tests? Preliminary investigations came up with more than 30 items that we needed to consider. The principle items are assuring safety; raising running speed; countering adverse environmental effects; raising passenger comfort; and other considerations.

First, I would like to mention R&D into raising running speeds. There are five main aspects to this work. One of the most important is developing a single pantograph that can collect electric current from the overhead catenary wire without generating excessive noise from wind turbulence effects, sparking, etc. Another aspect is how to develop compact lightweight high-capacity motor and drive systems that maintain good rail adhesion while running at high speed. Signalling systems and power supply systems are also very important aspects that must be solved to ensure high-speed operations.

Here, I would like to give a short description of the pantograph current collection system; Figure 5 gives some notes on the design of the overhead catenary and pantograph. One major hurdle that must be overcome is understanding the relationship between the catenary wire and the pantograph including the pressure of the collector plates on the wire, the separation rate, etc. For this reason, it is very important to maximize the design characteristics by considering

Figure 6 Improved Bogie Technologies

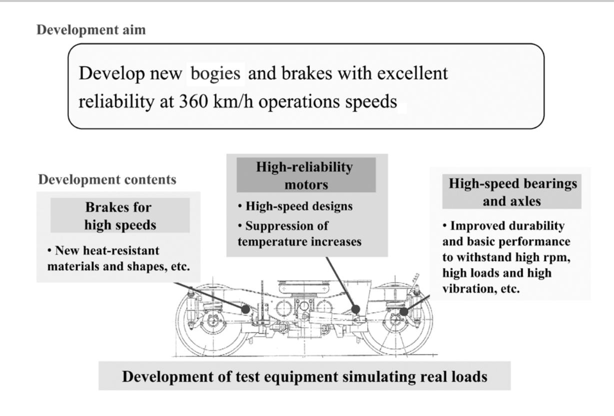
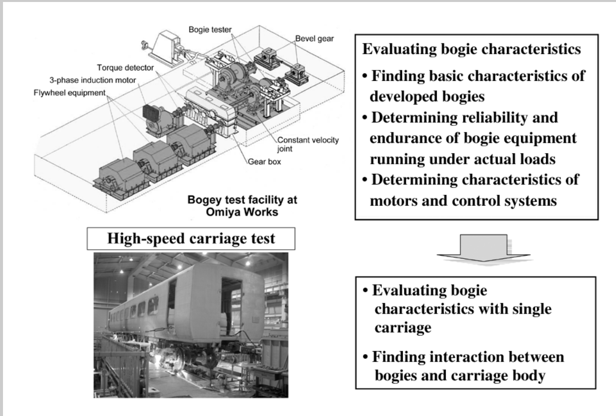


Figure 7 Bogie Test Facility



the catenary wire and pantograph as a single system. A test pantograph design with low noise generation characteristics and excellent wire following characteristics that collects current efficiently at high speeds is now moving from development to commercial operation.

We are progressing with development based our R&D roadmap. Development of a new pantograph is in progress as I have described, but we are currently thinking whether or not be about to add an active suspension system (active control) to the design. In the area of catenary design, we have been analyzing the current-collection characteristics of different wire designs and are performing tests on prototype designs to establish the important elements in catenary structures. The final stage will be actual on-site running tests and evaluations.

Next, I want to discuss how to ensure safety. The major elements in ensuring safety include bogie design, reliability of bogie-mounted parts with more efficient braking systems, earthquake and snow safety systems, better construction standards, side wind countermeasures, stronger tracks, aerodynamic design of rolling-stock, etc. Figure 6 shows improved reliability design of bogies running at high speeds, which experience higher axle revolutions and more vibration. To counter these problems, it is necessary to design bogies with better reliability and braking systems.

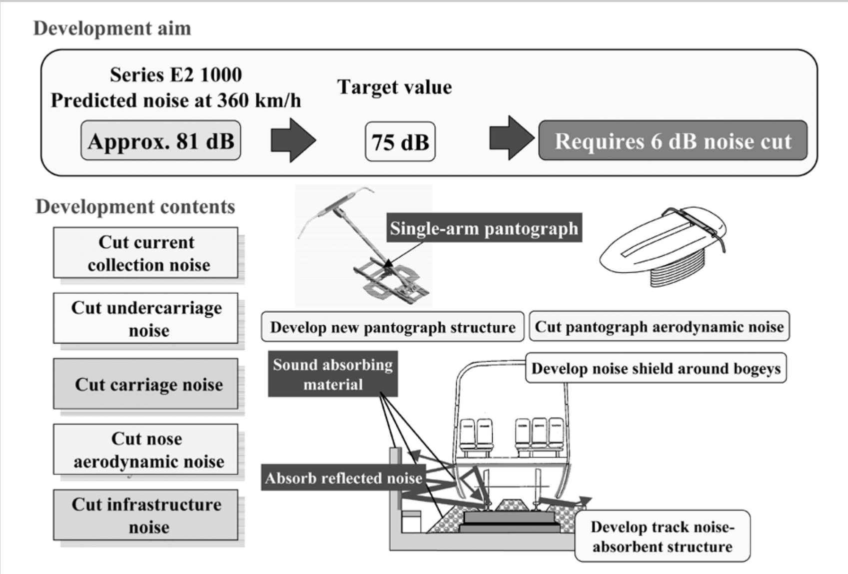
To give a concrete example, we need to progress with design of brakes, motors, and axle equipment that can all withstand the wear-and-tear of high-speed operations for long periods. This type of fundamental research aims to produce dramatic improvements in performance and requires quantitative testing with realistic loads as well as a variety of track trials.

To develop these high-speed bogies, we have finished constructing a bogie test facility (Fig. 7) this year. In line with this R&D into speed increases, this test facility will have equipment for simulating real track loads when bogies are running at 400 km/h, enabling us to determine the basic performance of the newly-developed bogies and the reliability and endurance characteristics of various bogie-mounted equipment.

In addition, the high-speed rolling-stock test equipment will also play a major role in understanding the relationship between the bogies and carriage body when running at high speed. Running stability tests have also been performed using cameras mounted under bogies and tracks in order to assist with development of better shinkansen tracks for the future.

Now I would like to turn to environmental measures. There are a number of major hurdles to be overcome by adopting breakthrough solutions. First, how can we suppress track-side noise caused by higher running speeds? Track-side noise is caused by a variety of factors, each of which requires thorough research. Figure 8 shows development concepts for suppressing track-side noise; when current rolling stock is running at 360 km/h, the predicted noise level is in the region of 81 dB. The legal standard is 75 dB so there is still a major hurdle to overcome in cutting noise levels by 6 dB. Research is progressing along a number of avenues but the most promising involve new pantograph designs and wind shields to cut the wind-generated noise as well as new ground structures such as side barriers to absorb undercarriage noise, etc. Research into low-noise pantograph designs for use on new rolling-stock is continuing using large wind tunnels and we are progressing to the next development stage. Future research targets are decided on the basis of an R&D roadmap and we are attempting to reduce total noise levels by building designs with low current-collection noise, low

Figure 8 Controlling Noise



aerodynamic noise, low undercarriage noise, and low track noise. Due to the complexity of noise solutions, progress is gradual. The procedures are the same as for work on catenary and pantograph systems and involve test evaluations as well as track trials.

Next, I want to touch upon methods for suppressing tunnel sound (air) pressure waves. Since shinkansen rolling stock runs at high speed, when a shinkansen train enters a tunnel with slab track, a pressure wave is generated and travels at extremely high speed through the tunnel to create a loud noise rather like a sonic boom at the tunnel exit. We have been studying how reduce this effect. When a modern train enters a tunnel at 360 km/h, the sound pressure wave increases by about 60%, so we are examining ways of reducing the wave propagation through the tunnel (Fig. 9). Tests have been conducted on the best shape for the train noise to reduce generation of the pressure wave (it was found to be a duckbill shape). Changes to the tunnel portal designs include a slotted baffle structure that helps attenuate the boom as the pressure wave exits the tunnel.

What about improving the ride comfort? Comfort is not simply related to operations speed, and one aim of current research is to improve comfort levels for passengers when travelling at even higher speeds. Problems to be tackled include horizontal and vertical vibration, in-carriage noise levels, and lateral centrifugal forces when travelling through curves, which can cause severe passenger discomfort and also force reductions in operation speeds, resulting in longer travel times. In addition, vertical track irregularities cause problems with adhesion to rails as well as excessive wear and tear.

To provide a comfortable ride, current rolling stock designs use methods such as active suspension, which are able to provide suitable comfort levels for current operations speeds. However, when future speeds rise to the level of 360 km/h, the predicted noise level will be around 85 dB, which is at least 5 dB higher than the 80 dB recommended as the maximum level by many train operators (Fig. 10). Clearly, new low-noise bogie designs are required; at present we are considering a new active damping technology for the active suspension system currently in use on the *Hayate* shinkansen trains operating

Figure 9 Controlling Tunnel Sound Pressure Wave

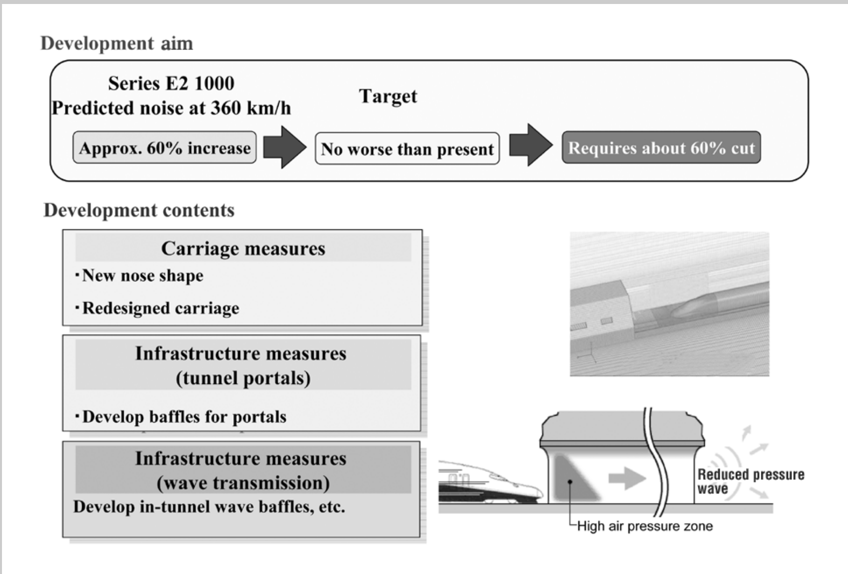


Figure 10 Improving Ride Comfort

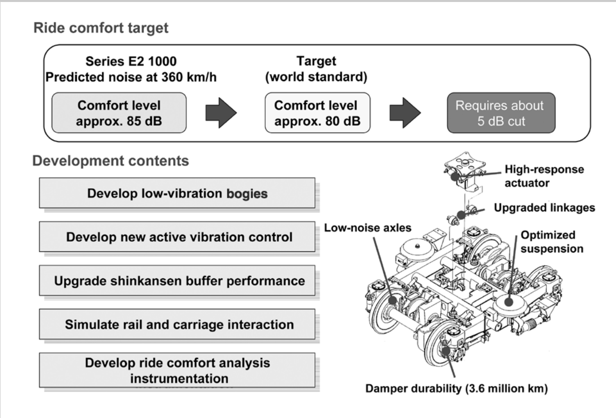
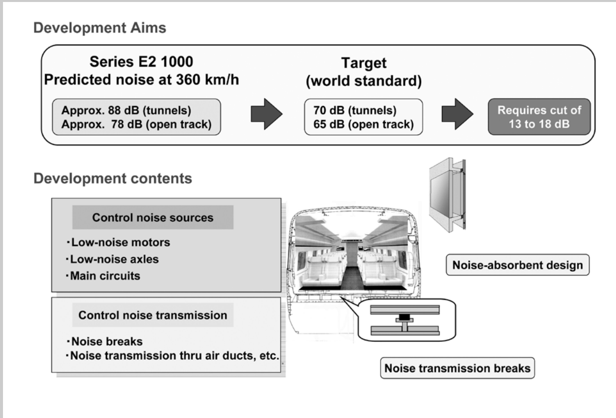


Figure 11 Cutting In-carriage Noise and Vibration



from Hachinohe. In addition, it may be necessary to consider new technologies based on track modifications and a series of tests have been performed with different combinations of bogies and carriages to observe the impact on track structures by measuring horizontal and vertical vibration as well as the effect of track curves. Working in cooperation with the Railway Technical Research Institute, we have been able to undertake the first tests of this type in Japan and, as a result, we are considering how to build the world's most comfortable shinkansen carriage.

Next, I want to mention in-carriage noise; current rolling stock operating at high speeds on open sections has in-carriage noise levels of around 78 decibels but the world recommended maximum noise level facilitating easy conversation is about 65 decibels (Fig. 11). This is a difficult hurdle to overcome principally because of the many sources of noise, and eliminating bogie running noise, noise between the rails and wheels, etc., will require solutions such as low-noise motors, noise-damping wheels, etc. This development will require a thorough re-examination of all noise sources within the train set, starting with noise-absorbent carriage structures.

We have looked at four of the five fields mentioned above, but I would also like to mention some other areas of research falling into the Other category. These include investigations into the effect of electromagnetic noise generated by high-speed running, guaranteeing on-time efficient operations, and suppressing increases in power consumption. Mr Masaru Ibuka, the founder of Sony Corporation, commented that development of unique new products first requires establishment of high targets. The next requirement is the full adoption of new technologies and the final requirement is challenging high hurdles. Without these attributes, he said it is not possible to develop unique new products. In meeting the future for railways we must always remember to develop new products meeting difficult challenges. To achieve high speeds, we need R&D into many technical fields related to railways, such as rolling stock, tracks, catenary, operations, maintenance, etc. The hurdles are high and the solutions will come from a wide range of technologies.

In recent years, great and rapid progress has been made in new technologies, such as electronics and new materials. To improve the technical level of railways we must consider how to best incorporate the latest advances and also plan for the future.

To promote research into speed increases JR East has established company-wide projects centred around our R&D Center; in particular, we have formed working groups aimed at tackling horizontal themes and difficult hurdles. However, increasing the speed of shinkansen operations requires a deep understanding and knowledge that cannot always be found in railways, and for this reason, we would very much like to establish joint research with industries, universities and research bodies worldwide. ■

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