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Fifty Years of the Shinkansen, and the Opening of the Hokuriku Shinkansen

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The Safety of the Shinkansen

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October 1, 2014 marked the passage of fifty years since the opening of the Tokaido Shinkansen (bullet train line), which was Japan's first Shinkansen, and also the world's first high-speed railway. Japan's Shinkansen network—which began with the 552.6 km stretch between the stations of Tokyo and Shin-Osaka—has continued to grow and expand and, including the new Hokuriku Shinkansen (between Nagano and Kanazawa) that entered service on March 14, 2015, has now reached a total length of 2,848.3 km. (See the table: Shinkansen)

The Shinkansen mentioned above are the ones capable of running at speeds of over 200 km/h. Apart from these, there are also the 275.9 km of the Yamagata and Akita Shinkansen, which are both of the type that run onto conventional train lines; the Hakata-Minami Line; and the 1.8 km stretch of the Joetsu Line between Echigo-Yuzawa and Gala-Yuzawa; which are also essentially part of the Shinkansen network. Including these, the overall length extends to 3,134.5 km. In addition, the construction of new Shinkansen lines is also continuing: the Hokkaido Shinkansen between Shin-Aomori and Sapporo, the Hokuriku Shinkansen between Kanazawa and Tsuruga, and the section of the Kyushu Shinkansen between Takeo-Onsen and Nagasaki (the "Nagasaki" or "West Kyushu" route). Together these add up to around 550 km of track, and by mid-way through this century a Shinkansen network covering a little over 3,600 km will have been constructed in Japan.

Mt. Fuji and the N700

Over a period of half a century, the number of people who have used the Shinkansen has grown to a total of 11.08037 billion. However, there has been not one accident in which a passenger has lost their life due to, for example, causes such as collision with another train, derailment or fire.

Although the probability of the occurrence of an accident is almost "zero,"

it would be premature to simply tidy things away with the so-called myth of safety, that the Shinkansen is absolutely safe and secure. The safety of the Shinkansen is not something that was brought about by coincidence or good fortune. Rather, it is something that has been accomplished as a result of the meticulous preparation of equipment and countermeasures to ensure safety from before the opening of the Tokaido Shinkansen, and the continual refinements that have been made repeatedly since its opening.

To understand just how superbly safe the Shinkansen really is, it is actually easier to make a deliberate point of introducing events that reflect negatively on the Shinkansen. The one I will raise here are the derailment accident that have taken place by a major earthquake.

The accident took place on October 23, 2004, between Urasa and Nagaoka on the Joetsu Shinkansen. On that day, the M 6.8 maximum intensity 7 Niigata-Chuetsu Earthquake occurred, derailing Toki 325, a train that was running near to the epicenter. Eight cars out of the ten-car configuration derailed, and in particular the body of car No.1 at the very rear (Tokyo end) of the train tilted heavily to its side, to the point that it was touching the neighboring tracks. Fortunately, however, there were no fatalities.

Directly before the earthquake, Toki 325 had been running at a speed of 204 km/h. The fact that a great catastrophe was prevented in spite of this was due to the work of a safety device called Compact UrEDAS. Compact UrEDAS is a system that detects the preliminary P wave micro-tremors produced by earthquakes, and automatically cuts off the electricity supply to the Shinkansen's overhead power lines when it judges that the main earthquake will be intensity 4 equivalent or higher. When the power supply to the train is interrupted, the ATC immediately attempts to stop the train.

In the case of Toki 325 on this day, the transmission of electrical power to the overhead lines was stopped one second after the preliminary P waves were detected, and 1.5 seconds after that the emergency brakes were applied by the ATC. It was another 1.2 seconds later that the major tremors of the main earthquake struck Toki 325. It could be said that this "saving" of 1.2 seconds prevented the worst-case scenario of the train overturning.

Image of vehicle (top) and lane deviation prevention device (Courtesy of JR Central)

But the East Japan Railway Company (JR East) was not satisfied with the way things were, and went on to make further improvements to the safety systems. The company strongly recognized the magnitude of the accident.

As a response to the accident, Compact UrEDAS was improved to the Earthquake Early Detection System for Shinkansen, a system with heightened precision and an increased rate of response. (Note: Earthquake Early Detection System for Shinkansen is the name given to the system by JR East. JR Tokai, JR West and JR Kyushu respectively call it the Tokaido Shinkansen Earthquake Early Warning System, the JR West Earthquake Early Detection & Warning System and the Anti-quake Train Protection System.) On the train side too, the time taken between power transmission being stopped and the

brakes being applied has also been shortened by around one second. In addition, efforts were made to stabilize the behavior of the trains as much as possible in order to avoid the worst-case scenario even in the event that the train does actually derail, incorporating various measures such as attaching anti-toppling guides and other devices to the tracks and to the trains themselves.

These countermeasures paid off when the Great East Japan Earthquake struck on March 11, 2011. Of the eleven trains that were running on the stretch of the Tohoku Shinkansen between Utsunomiya and Morioka, where the tremors were especially large, ten of the trains stopped safely. The remaining train was a test train that was not in service, and although two axels of one of the train's ten cars did derail, the effect of the guides ensured that the body of the car did not veer significantly from the tracks or tilt by a great amount. There were of course no fatalities, and not even a single passenger was hurt.

The "Hardware" and "Software" Supporting the Shinkansen's Tight Schedule

The number of Shinkansen trains running nationwide (as of March 31, 2014) has reached 842. Since Shinkansen trains (excluding both the Yamagata and Akita "mini" Shinkansen) run for 18 hours a day between the hours of 06:00 and 24:00—out of consideration for the rail-side environment—it can be calculated that a train is running on some Shinkansen somewhere every minute and 16 seconds.

Having this many trains running, on schedule, and at high speed requires appropriate systems. It goes without saying that ATC and systems that stop the trains automatically when there is a large earthquake—raised as examples in the previous section, "The Safety of the Shinkansen"—are essential. Apart from these, there are also various other systems and equipment working to support the running of the Shinkansen; such as devices that measure rainfall and wind-speed etc. and issue alerts when these measurements exceed standard values, and systems that manage records of the trains' inspection and repair histories.

Tokaido-Sanyo Shinkansen the General Control Center (Courtesy of JR Central)

If we were to make an analogy to human beings, the systems and devices mentioned above could be said to be the equivalent of nerves. Of course these are also essential for making the trains, or in human terms the hands and feet, run. But hands, feet and nerves all rely on the workings of the brain in order to function.

The Shinkansen also has what, in human terms, we would call a brain. This is the General Control Center, and the large-scale computer system that supports it.

The General Control Center fulfills the role of centrally managing the operational status of the trains and other systems and equipment, and of handing down appropriate instructions to the train crews, station attendants and other operational divisions in the event of any issues or abnormalities. In the case of the Tokaido-Sanyo Shinkansen the General Control Center has six departments: transport control (passengers), which is engaged in all aspects of passenger transport services; transport control (trains), which is responsible for train operation; operational control, which handles the operation of cars and crew, and responds to breakdowns; facilities control, which instructs the maintenance of tracks and other structures; power control, which in the same way handles power-related issues; and signal & telecommunications control, which similarly organizes work relating to signals and telecommunications equipment etc. Each section's controllers keep a close watch over their own particular area of responsibility, and work together in cooperation to ensure the continued safe and stable operation of the Shinkansen's trains.

What the controllers are mainly looking at are the monitors and indicator panels of a CTC (Centralized Traffic Control) device. These display various information, such as the positions of all the trains in their area of responsibility, the operational status of various equipment and devices installed on the ground, and also weather conditions along the train lines.

At the time that the Tokaido Shinkansen opened half a century ago, the controllers responsible for train operation would set the routes of trains manually when they entered a particular station—such as whether they would go onto a through route or a passing track/refuge siding)—while looking at the CTC indicator panels. This is still possible today; but with 300 or more trains running per day on the Tokaido Shinkansen alone, and with the trains taking various different routes, it is not realistic to rely on human hands. And so the current method, of inputting a diagrammatical representation of the day's train schedule into a large-scale computer in advance and setting the route automatically for each train, was adopted. In the case of the Tokaido-Sanyo Shinkansen, this kind of computer system is called COMTRAC (COMputer aided TRAffic Control system). For the Tohoku, Joetsu and Hokuriku Shinkansen it is called COSMOS (COmputerized Safety, Maintenance and Operation Systems of Shinkansen) and for the Kyushu Shinkansen it is called SIRIUS (Super Intelligent Resource and Innovated Utility for Shinkansen). COSMOS and SIRIUS perform not only routing control for the trains, but also handle the management of train cars and equipment. On the other hand, a computer system that manages cars and equipment—called SMIS (Shinkansen Management Information System, pronounced as an approximation of the English name "Smith" in Japanese)—has also been constructed for the Tokaido-Sanyo Shinkansen, and this works in conjunction with COMTRAC to support the functions of the General Command Center.

Computer systems are also effective when the train schedule is disrupted due to accidents, disasters and so on. They re-make the schedule according to the delays, and set new routes for the trains. That being said, it is not the case that everything is left entirely up to computers. In actual fact, much of the work to alter the train schedules is carried out by the human controllers. This is because, with the situation changing every moment, it is faster for the experienced controllers to make a new schedule themselves than to input various conditions into the computer. The computer takes a supporting role in checking whether that there are no inconsistencies in the completed schedule diagrams after they have been created in this way.

Service Aspects: From Onboard Service to the Cleaning of the Cars

From hardware to software, the Shinkansen can feel like just a mass of machinery, but a surprising amount of human warmth can be found in there too. If you ride the train, the conductors and onboard sales staff come and go between the seats, and if you are waiting to board a train preparing to head back in the opposite direction at a terminal station like Tokyo, you may witness the sight of a large crew of people cleaning the train cars.

While not only limited to the Shinkansen, there is deep-rooted criticism that service announcements onboard trains and in the stations of Japan's railways are excessive. One also hears the opinion that the successive comings and goings of conductors and onboard sales staff are bothersome and intrusive. It is difficult to strike a perfect balance between providing accurate information and the service of enabling passengers to purchase food and beverages where necessary, and maintaining a quiet in-train environment and respecting passenger privacy. But this kind of effort is constantly taking place.

Firstly, let us look at the conductors. From the time of the opening of the Tokaido Shinkansen up until the 2000s, it was customary for them to check whether or not each passenger was carrying the correct ticket, or formally, to perform the onboard ticket collection. While having the advantage of being able to give detailed information by speaking individually with each passenger, there were also apparently many voices of dissatisfaction.

On entering the 2000s, technological advances rendered onboard ticket collection unnecessary. When passengers pass through the automatic ticket gates, information about their tickets is sent to the portable device carried by the conductor, and their boarding status is displayed on a seating chart. The conductor then compares the seating chart on their portable handset with the actual seats. It has now become sufficient to approach only customers who are sitting in a seat in spite of there being no boarding information for that seat shown on the seating chart.

However, in the case of the Tokaido Shinkansen, on board ticket inspections are conducted for the reason that there are many passengers who change their tickets and board another train due to various circumstances. The portable handsets can of course be utilized, but it is said that the ticket inspection is carried out more as a part of a service to avoid trouble taking place between fellow passengers over seats.

With onboard sales staff, it is necessary for them not to be a disturbance to passengers, while at the same time making a definite appeal about their presence to those wishing to make purchases.

Also, due to reasons relating to the direction in which seats are facing, there are many cases in which passengers have their backs turned to the sales staff. In order to handle these conditions, the business operators that provide onboard sales staff have training facilities that simulate the interior of the trains, and use them to build up sales training experience.

The interior cleaning of the trains is an area that can surely be said to have undergone a rapid and continuous evolution since the opening of the Tokaido Shinkansen. Today, in the shortest cases, JR East Shinkansen trains at Tokyo station begin their journeys back in the opposite direction after just seven minutes. This is a result of the skill of the cleaning staff, who complete the cleaning of the insides of the trains with efficiency and finesse.

They find out quickly where garbage has been dropped in the passenger cabin, and make use of special techniques, such as cleaning two of the tables attached to the backrests of the seats in one go. Support on the equipment and systems front, such as devices which automatically rotate the seats, and the elimination of the need to clean ashtrays by making all passenger cabins non-smoking, cannot be overlooked either.

The skills of the experts mentioned above, who are encountered when using the Shinkansen, is also rated highly overseas, to the extent that comments are heard from the leaders of countries constructing high-speed rail networks, saying that they would like to "import" these skills.

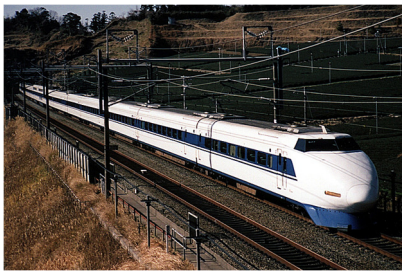
The Trains: Evolving from the 0 Series to the E7 / W7 Series

The vehicles that were first to be put into service at the time of the opening of the Tokaido Shinkansen were called the 0 series. After that, the 100, 300, 500 and 700 series were successively introduced on the Tokaido-Sanyo Shinkansen, with the latest vehicle being the N700 series. The vehicles on the Tohoku, Joetsu and Hokuriku Shinkansen began with the 200 series, and progressed through the 400, E1, E2, E3 and E4 series. The latest set of vehicles made for the Tohoku Shinkansen is the E5 series, for the Hokuriku Shinkansen the E7 / W7 series, and for the Akita Shinkansen the E6 series. The Kyushu Shinkansen began with the 800 series, and the N700 series was also added later.

If you compare the 0 series vehicles with the latest models, the signs of evolution are apparent at a glance. The body surfaces of the vehicles have been shaped into a smooth finish, and virtually no protrusions can be seen. The clearance heights of the vehicles have also become lower, and the shapes of the head sections have come to trace increasingly complex curves. The 0 series had one pantograph (a device for drawing electrical power from the overhead lines) every other vehicle, but the latest vehicles have much fewer, having only one or two for a 7–16 car arrangement. This not only lowers air resistance, making it easier to increase speed, but also gives the added benefit of reducing noise and vibrations when the train is in motion.

In countries like Japan that have a high population density, there is a tendency for Shinkansen tracks to run close to residential areas. The Japanese Environment Agency (currently the Ministry of the


0 Series


100 Series


300 (left) and 500 Series


N700 (left) and 700 Series


E5 Series
All Photos: PIXTA

Environment) has set strict regulations for noise and vibration levels produced by Shinkansen trains, at 70 phon or below for residential districts, and 75 phon or below for quasi-residential areas.

For a period during the 1970s, the top speed of the Shinkansen was kept down to 210 km/h. However, in the mid-1980s, the dedicated research efforts that had continued up until that time brought forth results, and the implementation of a speed increase was also due to the successful development of vehicles producing low levels of noise and vibration.

Because the vehicles are painted you cannot tell at a glance, but the material used for the 0 series and for the latest trains is different, too. In contrast to the 0 series, which had an iron and steel construction, the latest vehicles are all made from a lighter-weight aluminum alloy. Making the vehicles lighter reduces vibration when the trains are in motion. In addition, since the load on the tracks can be reduced, this can also be linked to savings on construction and maintenance costs. Because power consumption can also be suppressed, they are also highly energy-efficient.

The shapes of the vehicles' head sections have the characteristic of being more complex the more recent the model is, and the lower part has also become quite bloated. This is a measure for the purpose of reducing the impact noise produced when the train enters a tunnel. Because Japan is a mountainous country and numerous tunnels must be constructed along the Shinkansen tracks, it is essential for the trains to be this shape. It must not be forgotten that the manufacture of these head sections are the achievements of computer analysis, and of the manufacturing personnel who build them up, with unerring accuracy, from the design plans obtained as a result of that analysis.

The Characteristics of the Hokuriku Shinkansen

E7 / W7 Series
Photo: PIXTA

The Hokuriku Shinkansen running the 228.1 km between Nagano and Kanazawa, which opened on March 14, 2015, has several characteristics that cannot be seen in other Shinkansen. It runs through deep mountain gorges and areas of heavy snowfall, and the power supply frequency of the 25,000-volt alternating current flowing through its overhead lines fluctuates drastically along the way.

The deep mountain area between Nagano and Itoigawa, what could be called the "backbone" of the Japanese archipelago, has inclined sections with up to 3% gradients. These 3% inclines—for which a height difference of 3 m arises for every 100 m progressed—may not present such a hardship for an automobile, but when the friction between the wheels and the rails is low as with a railway, and even more so with the Shinkansen, where the train is running at high speed, they are a difficult spot.

The E7 / W7 series trains used on the Hokuriku Shinkansen are equipped with four 300 kW motors per car, and with the powerful driving force of 10 motorized cars per 12 car configuration,

have the capability of racing up 3% slopes at speeds of at least 200 km/h. On the other hand, 3% gradients are also tough when going downhill too. In order to prevent accidents caused by excessive speed, the E7 / W7 series are equipped with speed-suppressing brakes, which apply a constant breaking force and maintain a speed of 210 km/h. Because of concerns over the overheating of the brake shoes that would be caused by disc brakes, which rely on friction, a regenerative braking system was adopted. This regenerative braking system operates the motors as electrical generators and uses the heat energy produced—which creates a large resistance—for braking power. Because the electrical power generated by the motors is returned to the overhead lines and can be used by other trains, it is also useful for energy conservation.

Excluding a partial section around the outskirts of Nagano, the stretch between Nagano and Kanazawa is a heavily snowy area, with snowfalls of at least 115 cm or more for the last decade. For that reason, thorough snow clearing measures are being taken.

Between Nagano and Itoigawa, where the most severe snowfalls of 220 cm or more have occurred over the last ten years, sprinklers have been installed at the sides of the track, dispersing large volumes of water and washing the snow away. Essentially, the amount of snow on the stretch between Itoigawa and Kanazawa would also require sprinklers, but because there are no rivers running parallel to the track that would serve as the water source for the sprinklers they cannot be installed. Because of this, a system was adopted whereby the E7 / W7 series trains plow their own way through the snow, or, in cases where the snow cannot be cleared in this way, a dedicated snow clearing vehicle is mobilized. This kind of system is a first for the Shinkansen. The distinguishing feature is the preparation of pocket-shaped spaces to either side of the tracks on the viaduct (the elevated structure that supports the tracks) for collecting the snow blown aside by the snow clearer.

Japan is a single country in which the frequency of the AC electrical supply varies depending on the power company supplying it. Broadly speaking, in eastern Japan it is 50 Hz, and in western Japan it is 60 Hz.

Because the Hokuriku Shinkansen between Nagano and Kanazawa was laid along the frontier between East and West Japan, the distribution of frequencies is complex. Specifically, between Nagano and the vicinity of Joetsumyoko the frequency is 60 Hz; between the vicinity of Joetsumyoko and that of Itoigawa it is 50 Hz, and between the vicinity of Itoigawa and Kanazawa it is 60 Hz.

As far as the power supply required by the motors of the E7 / W7 series is concerned, the motors can function properly with either a 50 Hz or a 60 Hz supply, but they are affected by issues such as changes in the rotational speed of the cooling fans for the motors and so on. Therefore, the E7 / W7 series employs a mechanism which uses a supplementary power supply unit that combines a converter and an inverter to generate a constant 60 Hz, 440 V three-phase alternating current, irrespective of whether the electrical power drawn by from the overhead lines is at 50 Hz or 60 Hz, and uses this to supply power to the fans.

On the other hand, countermeasures have also been applied to the overhead lines themselves. When the electrical supply from the power company to the 50 Hz section sandwiched between 60 Hz sections on either side is interrupted, it is not possible to accept power from the neighboring sections for relief purposes. Therefore, the power-related equipment and facilities in the 50 Hz section have been purposefully made to specifications that can use both 50 Hz and 60 Hz supplies, enabling them to supply power at 60Hz from the neighboring section to the overhead lines in the event of

abnormalities.

Steep gradients, areas of heavy snowfall and varying electrical supply frequencies: these are characteristics that can only be seen on Japan's Shinkansen. The Hokuriku Shinkansen races around at top speeds of up to 260 km/h, bearing handicaps that do not exist on high-speed railways in any other country.

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Table: Shinkansen

Shinkansen Lines (Lines operating at regular service speeds of 200 km/h or higher regular service speed)

JR company	Line	Section	Length (km)	Opened	Remarks
JR Central	Tokaido Shinkansen	Tokyo - Shin-Osaka	552.6	October 1, 1964	
Total			552.6		
JR West	Sanyo Shinkansen	Shin-Osaka - Hakata	644.0		
		Shin-Osaka - Okayama	180.3	March 15, 1972	
		Okayama - Hakata	463.7	March 10, 1975	
	Hokuriku Shinkansen	Joetsu-Myoko - Kanazawa	168.6	March 14, 2015	
Total			812.6		
JR East	Tohoku Shinkansen	Tokyo - Aomori	713.7		
		Omiya - Morioka	505.0	June 23, 1982	
		Ueno - Omiya	26.7	March 14, 1985	
		Tokyo - Ueno	3.6	June 20, 1991	
		Morioka - Hachinohe	96.6	December 1, 2002	
		Hachinohe - Shin-Aomori	81.8	December 4, 2010	
	Joetsu Shinkansen	Omiya - Niigata	303.6	November 15, 1982	
	Hokuriku Shinkansen	Takasaki - Joetsu-Myoko	176.9		
		Takasaki - Nagano	117.4	October 1, 1997	
		Nagano - Joetsu-Myoko	59.5	March 14, 2015	
Total			1,194.2		
JR Kyushu	Kyushu Shinkansen	Hakata - Kagoshima-Chuo	288.9		
		Hakata - Shin-Yatsushiro	137.6	March 12, 2011	
		Shin-Yatsushiro - Kagoshima-Chuo	151.3	March 13, 2004	
Total			288.9		
Grand total			2,848.3		

Through Trains (Mini-Shinkansen)

JR company	Line	Section	Length (km)	Opened	Remarks
JR East	Yamagata Shinkansen	Fukushima - Shinjo	148.6		This section is called the Ou Line under the Railway Business Act
		Fukushima - Yamagata	87.1	July 1, 1992	
		Yamagata - Shinjo	61.5	December 4, 1999	
	Akita Shinkansen	Morioka - Akita	127.3	March 22, 1997	The section between Omagari and Morioka is called the Tazawako Line. The Omagari - Akita section is called the Ou Line under the Railway Business Act.
Total			275.9		
Total length of Shinkansen and Mini-Shinkansen lines			3,124.2		

Other Shinkansen

JR company	Line	Section	Length (km)	Opened	Remarks
JR West	Hakata Minami Line	Hakata - Hakata-Minami	8.5	April 1, 1990	This section is virtually a part of Sanyo Shinkansen
JR East	Joetsu Line	Echigo-Yuzawa - Gala-Yuzawa	1.8	December 20, 1990	This section is virtually a part of Joetsu Shinkansen
Total			10.3		
Grand total			3,134.5		

Shinkansen Lines Under Construction

JR company	Line	Section	Length (km)	Expected start of revenue services	Remarks
JR Hokkaido	Hokkaido Shinkansen	Shin-Aomori - Sapporo	360.0		
		Shin-Aomori - Shin-Hakodate-Hokuto	149.0	Around spring of 2016	
		Shin-Hakodate-Hokuto - Sapporo	211.0	Around 2031	
Total			360.0		
JR West	Hokuriku Shinkansen	Kanazawa - Tsuruga	125.2	Around 2023	
Total			125.2		
JR Kyushu	Kyushu Shinkansen	Takeo-Onsen - Nagasaki	66.0	Around 2022	Gauge-adaptable train cars are planned for the section between Shin-Tosu and Takeo-Onsen.
Total			66.0		
Grand total			551.2		