# Japanese Railway Safety and the Technology of the Day

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## Introduction

Safety is the most important condition for railway companies worldwide. Following the opening of Japan's first railway in 1872, a great deal of attention and effort has been paid to making railway operations safe. Despite these best efforts, accidents still occurred, shaking people's faith in safety. And each time an accident occurred, further safety measures were taken. Today's railway safety is based on the many bitter experiences of the past.

The first railways in Japan were single track and used steam locomotives to haul the carriages. Train collisions were prevented by dispatching trains at fixed time intervals (headway) and fixed distance intervals. Speeds were limited to about 20 miles per hour. Only the locomotive had steam brakes—the passenger carriages and freight wagons just had hand brakes. Accidents were prevented by telegraphic messages between stations and there were some mechanical signals too.

This forms a sharp contrast to today's Japanese railways with an extensive network of shinkansen serving most major cities with safe and punctual high-speed services. The 130-year history of Japan's railways, especially on-time arrivals, accurate operations, and safety, has played a major role in the nation's social development. These achievements are mostly based on development and combination of various new technologies and on improving employees' skills.

This article discusses how railway accidents are related to the technologies of the period and explains how safety can be improved even further by studying past railway accidents.

## Technical Interface and Overall View

Railways can be considered to be a one-dimensional transport mode in which trains run along a fixed path. In contrast, the automotive and shipping modes are two dimensional and the aviation mode is three dimensional. Each mode has a unique system of integrated technologies and even railways require a well-balanced combination of technologies to assure safe and punctual operations. In other words, the interface between technologies is important and an overall view of different technologies is very important too. Many past accidents occurred because this concept was lacking.

## Safety in Nation's Consciousness

Railways are deeply rooted in society and people's consciousness worldwide and they are also strongly influenced by the each nation's social, cultural and geographical climate. The Japanese archipelago stretches across a wide range of latitudes; it experiences great seasonal extremes of weather and some 40% of the country suffers from heavy winter snowfalls. Volcanoes and earthquakes are common and typhoons in the summer and autumn cause widespread damage. The traditional agriculture is based on rice-paddy cultivation, which requires sharing of water resources and communal irrigation by villages. This communal concept remains deeply rooted in the Japanese psyche even today.

Japan of 130 years ago was still a feudal society based on these types of communal activities. It was divided into various social ranks, ranging from the higher-class samurai (warrior) caste to the lower-class farmers, artisans and merchants. Each of the some 200 regional fiefs was under the control of a daimyo or lord. Edo (today's Tokyo) was the seat of the ruling Tokugawa shogunate and the centre of political and administrative power. The shogunate assured its central grip on power by obliging each daimyo to live with his family and retainers in an Edo residence every other year. As a consequence, Edo became central to the nation's political and economic life with post roads radiating towards all corners of the country. The regular passage of the daimyo with their many samurai and servants to and from Edo lead to inns, accommodations and villages springing up along the waysides. Japanese railways were built to follow such main roads, unlike in America where they crossed vast unpopulated prairies, etc.

## Development of Early Railways

Japan's first railway was opened in 1872 between Shimbashi in Tokyo and Yokohama. At that time, the population of Japan was 30.1 million about 65% of whom were literate but knowledge of science and technology was poor due to the strong influence of Confucianism from China.

Following the collapse of feudalism and the restoration of the Meiji Emperor (1852–1912) to power in 1868, construction of a railway network was started to unify the nation and reinforce central authority. Perhaps part of the Japanese methodical character and penchant for punctuality comes from this earlier age!

## The Age of Railway Construction

Early Japanese railways were constructed as an important tool in unifying the nation after the collapse of the 265-year old Tokugawa shogunate. At that time, Great Britain lead the world in railway technology and British railway engineers played a key role in building the first line between Shimbashi and Yokohama and then between Kobe, Osaka and Kyoto.

At the start, all the metal parts, such as the locomotives, rails, etc., were imported because Japanese metalworking technologies were poor. Edmund Morel (1841–71), the first engineer-in-chief for railway construction to the Japanese government at the time, is reported as saying that Japanese had a good understanding of civil engineering technologies such as embankments because this knowledge had been acquired during the feudal period when castle building was at its highpoint.

So when the first line started operating between Shimbashi and Yokohama in October 1872, how were accidents prevented? The basic principle is that, if there are two trains running in the same direction, the second train is permitted to depart after a certain length of time (fixed-time interval method). To allow two trains running in opposite directions on a single-track line to pass each other, the running times between stations were measured and a train diagram was drawn so that the approaching trains could cross at a previously determined station.

Rules were established and training was given to train crews and railway staff to protect the safety of the trains. This type of duty-based safety system is not unexpected given the samurai spirit of loyalty and total devotion to his lord that prevailed for hundreds of years during the feudal period.

Some of the relevant rules are listed below and were promulgated on 3 October 1873 as the Railway Train Operation Rules (Tetsudoryo Kishya Un'yu Kitei).

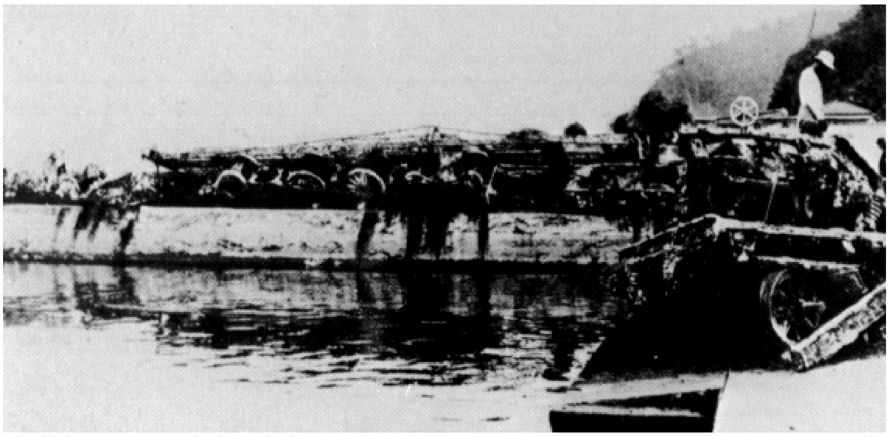
*Article 8*

This rulebook shall be provided to all persons related to train operations and track work who shall read the rules carefully and shall memorize them. This rulebook shall be carried at all times while working and shall be referenced as necessary.

*Article 92*

Train drivers and firemen shall always carry the train timetable and shall maintain the correct speeds. Speeds shall not exceed 20 miles per hour.

In addition, Article 9 also established a rule that the stationmaster could not allow a train to depart until he had received a telegraphic message from the stationmaster up the line indicating that the ahead track section was clear. However, the problem with this fixed-time-interval method of controlling track entry is coordinating the station arrival times of trains running in opposite directions—a train running late in one direction causes serious delays to trains running in the opposite direction. But allowing a train to depart without receiving the telegraphic message is dangerous and confusion in the train diagrams or train operation intervals runs a serious risk of causing a head-on train crash. To remedy such deficiencies, an additional telegraphic circuit to dispatch operational commands was soon introduced, but there were still fears about sending and receiving mistakes.



Train derailed by ground collapse while entering Nebukawa Station on Tokaido main line during Great Kanto Earthquake (1923). The train overturned and rolled down a cliff into the sea. (*JNR Centennial Photo History*)

## Early Accidents due to Operations Errors

The first fatal railway accident in Japan occurred on 1 October 1877 when a train on the up line to Osaka from Kobe was involved in a head-on collision with an out-of-service train on the down line, killing three people. At first sight, the accident was due to a misunderstanding on the part of the driver of the down train and the Nishinomiya stationmaster in confirming a change in the scheduled passing station, but it was actually an inherent problem with safety when using the fixed-time-interval method of scheduling train departures.

*Rear-end collision on 27 November 1883*

The next serious accident occurred on the Tokaido main line on 27 November 1883 when a freight train stopped on the down line just outside the entry signal for Ibaraki Station in Osaka Prefecture was hit from behind by a following passenger train, seriously injuring 8 people. To prevent the possibility of this type of accident happening again, new rear-end protection rules were implemented.

*Push operation derailment on 13 October 1885*

At Omori Station (Tokyo) on the Tokaido main line, 7 people were killed when a carriage of an unscheduled train being pushed by a locomotive to make the return run, derailed and overturned.

New safety measures were implemented each time these types of accidents occurred. Since the fixed-time-interval method of scheduling train departures was inherently dangerous, the token and tablet and the block telegraph methods were gradually introduced to help reduce these types of accidents. In fact, the token and tablet method continued in widespread use on single-track lines until quite recently. Nowadays, nearly all track sections in Japan use automatic block systems as well as Automatic Train Stop (ATS) systems. Consequently, token and tablet systems that secure train safety by relying on unreliable human attentiveness have mostly disappeared.

## Safety Measures on Trunk Lines

By 1869, the government railways were operating main lines between Tokyo and Kobe, Takasaki and Niigata, Maibara and Toyama, and Fukushima and Aomori. In addition, work was progressing on building links between Temiya and Wakkanai in Hokkaido, Ueno (Tokyo) and Aomori, Kobe and Shimonoseki, Nagoya, Nara and Osaka in Honshu and Hakata in Kyushu. Most government railways were built using British designs and methods but lines in Hokkaido and the San'yo Railway (Kobe–Shimonoseki) used American technologies while lines in Kyushu used German methods.

The growth of the network led to more trains running at higher speeds with an inevitable increase in accidents. Accidents were commonly due to train crew and staff signal mistakes, leading to the introduction of interlocking between signal equipment and points. The first mechanical interlocking was installed at Shinagawa Station (Tokyo) in 1887. Mechanical interlocking resulted in overall increases in safety levels and revision of the operation rules outlined as follows:

- Implementation of daily track inspections
- Setting of speed limits for down grades

This was related to the down grade (per mill) and the proportion of rolling stock with brakes (quite a few passenger carriages and wagons at that time had no brakes).

- Provision of through air brakes on trains running at average speeds exceeding 30 miles per hour
- Implementation of 3-yearly periodic inspections for steam locomotives
- Implementation of periodic inspections every 18 months and 3 years for passenger carriages and freight wagons, respectively
- Limitation of train push operations to 12 miles per hour or less
- Implementation of a speed limit of 10 miles per hour at turnouts
- Implementation of a speed limit of 15 miles per hour for reversing tender locomotives

## Railway Nationalization

In 1906 and 1907, the government nationalized most of the private railways to create a government railways network of about 7150 km. This permitted creation of an integrated transport plan. The prior separate management of private and government lines had made through operations difficult and there were also large differences in transportation capacity between different track sections. As a consequence of the nationalization, there was a need both for standardized locomotive designs to serve the new national network and for standardized track specifications to handle increased capacity and higher speeds.

Accident prevention is the most important theme for every transportation mode and is often based on many bitter experiences, some of which are described below.

## Natural Disasters and Train Safety Measures

The Japanese archipelago suffers many earthquakes, typhoons, volcanic eruptions and flooding. Based on the accidents described below, the civil construction codes are designed to handle natural disasters with heavy emphasis on earthquake-resistant design. The codes also incorporate a great deal of experience in resisting both typhoons and flooding.

### Typhoon and flooding railway accidents

*Typhoon derailment on 30 June 1899*

Twenty-five people suffered injuries when five passenger carriages of a train running on the down line of the Tokaido main line between Goyu and Gamagori in Aichi Prefecture were hit by typhoon winds and derailed to roll down an embankment. The accident was apparently due to a typhoon, but actually it was due to poor weather forecasting.

*Typhoon derailment on 7 October 1899*

Twenty people were killed and 45 injured when a train composed of seven passenger carriages and 11 freight wagons was hit by side winds from a typhoon while crossing a bridge between Yaita and Nozaki stations in Tochigi Prefecture on the Tohoku main line (then owned by Nippon Railway) and fell into the river below.

This accident caused major social problems that were soon picked up in the National Diet. Some of the dead were washed away by the flood-swollen river and were never found. The victim's relatives started a civil suit and the bitter courtroom dispute pointed out that the train operation should have been stopped after receiving the weather reports.

Nippon Railway lost the first round of the court case but reached a court-mediated settlement in the second round.

*Side-wind derailment on 23 September 1926*

Thirty-four people were killed and 39 injured when a limited express bound for Shimonoseki from Tokyo on the

San'yo main line derailed in a typhoon between Aki-nakano and Kaidaichi in Hiroshima Prefecture. The derailment was caused when an embankment collapsed due to heavy downpour from a typhoon and the tracks were washed away by the swollen river.
The accident report concluded that the accident occurred because the track inspection was insufficient for heavy downpours and because the railway had not examined the operation conditions for typhoons. In addition, public opinion put heavy blame on this accident to one of Japan's best international express services. The wooden carriages used at the time played a large part in the injuries and construction of passenger carriages changed to an all-metal design from 1927.

*Typhoon derailment on 21 September 1934*

An express train travelling between Kusatsu and Ishiyama on the Tokaido main line was derailed in Shiga Prefecture and turned over on the Setagawa railway bridge when it was hit by high typhoon winds of 41 m/s while running in winds exceeding normal wind-speed rules. Sixteen people were killed and 216 injured. There was a mistake in judging the weather conditions and relaying the information. In addition, unclear operation rules played a large part in the accident occurrence. As a result, anemometers were installed at high-risk locations and the operation rules were revised.

*Train collision on15 June 1938*

A night train bound for Kyoto from Shimonoseki on the up line of the San'yo main line derailed and overturned between Wake and Kumayama and was then hit by another train bound for Uno from Kyoto on the down line, killing 25 people and injuring 108. Heavy downpours from a typhoon caused a bank to collapse resulting in the locomotive derailing and overturning before being struck by the oncoming train. The accident was caused by problems with the track inspection and instructions to suspend operations.

Two passenger trains in head-on collision between Shimoda and Furumagi stations on Tohoku main line (29 November 1916). The accident was due to a token error at Furumagi Station. (*JNR CPH*)

### Earthquake-related accidents

*Great Kanto Earthquake at 11:59 on 11 January 1923*

The Great Kanto Earthquake with a Richter magnitude of more than 8.0 struck the Atami coast line along Sagami Bay south of Tokyo, causing widespread fires and devastation from Numazu through Yokohama to Tokyo. Twelve railway accidents were caused by the earthquake, but the worst loss of life occurred when a train on the down line of what is today's Tokaido main line was entering Nebukawa Station. The ground collapse derailed the train, which overturned and rolled down a cliff into the sea, killing 112 people and injuring 13 others.

## Accidents Caused by Staff and Crew Errors and Mistakes

Increasing train speeds and higher operations frequency coupled with small operations mistakes have been the cause of many railway tragedies as described below.

*Token error causing head-on collision on 29 November 1916*

Two passenger trains collided head on between Shimoda and Furumagi in Aomori Prefecture on the single-track Tohoku main line, killing 20 people and injuring 180 others. The accident happened because after the track section was blocked, a member of the Furumagi Station staff with no operations qualifications tried to take a token from the block instrument due to a misunderstanding. The machine was locked because the other token had already been removed at Shimoda Station and he wrongly concluded that there was a fault in the block instrument. He inserted a lever against the rules to remove the token, which was given to the engine driver. As a result, the up train departed from Furumagi Station and collided head on with the down train from Shimoda Station.

*Misread signal aspect on 25 April 1930*

Thirteen people were injured when an express on the down line of the Tokaido main line was passing an ahead train at Ishiyama Station. The accident occurred because the train driver misread the yellow aspect signal for proceeding with caution on the centre track as meaning proceed on the main line. His failure to slow down caused the train to jump the points, resulting in derailment and overturning.

*Points derailment on 12 January 1931*

Seven people were killed and 190 injured when an express passing through Kochi Station in Hiroshima Prefecture on the San'yo main line jumped the points, and overturned into a river. The accident happened because the driver had made a mistake about the speed limit and took the points at 80 km/h.

*Signal accident on 29 July 1937*

In this accident, a train passing through Okayama Station on the San'yo main line crashed into a stopped limited express train, killing 6 people and injuring 64. The accident was attributed to misoperation of the station entry signal.

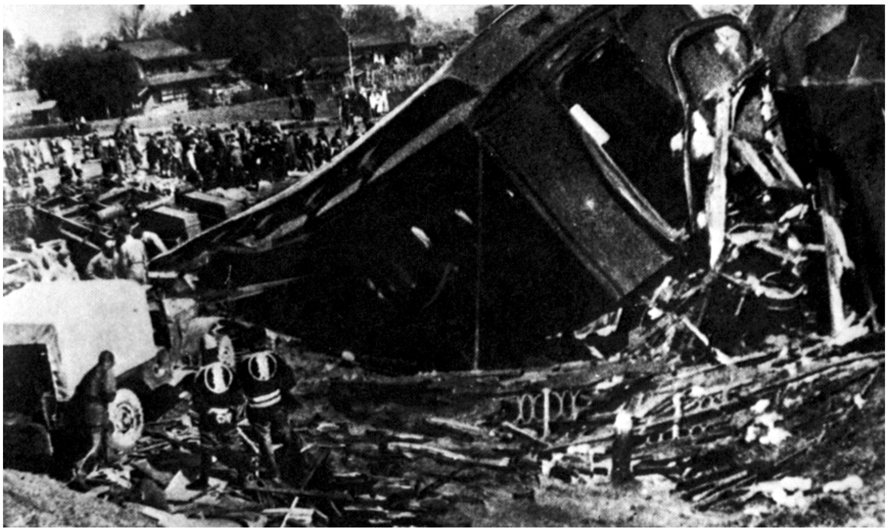
*Multiple mixed collision due to misread signal aspect on 26 March 1941*

This accident occurred at Tsukamoto Station in Osaka on the quadruple-tracked Tokaido main line when a freight train was about to enter the main down line from the Osaka northern freight bypass line after the driver misread the stop signal aspect. The freight train entered the safety siding and derailed, blocking both the up and down lines. Within seconds, a steam train arrived on the down passenger line along with another EMU on the down electrified line and both collided with the derailed freight train, killing three people and injuring 147 others.

The accident was caused by the driver of the freight train misreading the stop signal aspect.

*Collision due to driver misreading signal aspect on16 September 1941*

Sixty-five people were killed and 110 injured when an express train running at 85 km/h on the up line of the San'yo main line ploughed into a train stopped at Aboshi Station in Hyogo Prefecture after the driver of the express misread a signal aspect.



Train derailed off bridge between Higashi Hanno and Komagawa on Hachiko Line (25 February 1946). The accident was due to failure of worn-out rolling stock. (*JNR CPH*)

*Wartime accident due to worn out signal equipment on 29 October 1943*

Inexperienced staff and worn-out equipment during WWII caused a major collision at Tsuchiura Station in Ibaraki Prefecture on the Joban Line, killing 57 people and injuring 77. The accident happened when a signal error routed freight wagons being shunted in Tsuchiura Station on to the main line where they were hit by a freight train on the up line. The locomotive and wagons derailed to block the down line. A few seconds later, a passenger train arrived on the down line to collide with the derailed stock. The fourth passenger carriage fell off a railway bridge into the river below causing huge loss of life-it is easy to imagine the awful explosion of steam from the three overturned locos. It was concluded that inexperienced staff, and lack of signal interlocking and communications equipment caused the accident.

## Frequent Accidents due to Wartime and Postwar Damage and Shortages

*Locomotive explosions in 1945*

In one accident, a combustion chamber weld burst on the D52-82 wartime austerity design as it was passing through Mantomi Station in Okayama Prefecture on the San'yo main line. Similar explosions occurred in October 1945 on the D52-209 while passing through Samegai Station in Shiga Prefecture on the Tokaido main line and in December of the same year on the D52-371 as it was running on the Yoshinaga–Mitsuishi section of the San'yo main line in Okayama Prefecture. All were attributed to bad workmanship using poor-quality metal materials and welding rods.

*Stationmaster mistake on 27 August 1945*

This tragic accident just after the end of the war took the lives of 105 people and injured 67 when a lightning bolt damaged communications on the single-track section between Komiya and Haijima in west Tokyo on the Hachiko Line. Trains departed from each station in the up and down directions without appropriate blocking procedures. They collided head on while crossing the Tamagawa railway bridge and fell into the river below. The accident was attributed to the inexperienced stationmaster and other staff.

*Buffer overrun on 6 September 1945*

Sixty people were killed and 90 injured when a train overran the buffer stops at Sasago Station in Yamanashi Prefecture on the Chuo main line and struck a cliff face. The accident was caused by an inexperienced train driver failing to operate the brakes correctly.

*Over-speeding and overloading derailment on 25 February 1946*

In this major accident, a train derailed while taking a curve too fast as it was speeding down a 20 per mill grade on the down line between Higashi Hanno and Komagawa in west Tokyo on the Hachiko Line. The derailed out-of-control train fell 5 m off a railway bridge killing 184 people and injuring 495. The accident was attributed to use of old worn-out rolling stock built with poor-quality wartime materials and to passenger overloading. In addition, the train driver had received insufficient training.

Two trains in collision at Rokken Station on Sangu Line (15 October 1956). The collision was due to the train driver misreading a signal and insufficient braking power. (*JNR CPH*)

*Train fire on 24 April 1951 due to low design standards*

This train fire at Sakuragicho Station (Yokohama) on the Keihin Line happened when a short circuit occurred in the overhead catenary during power maintenance work. The electric sparks set fire to an arriving train and the conflagration spread quickly to take the lives of 106 people and leave another 92 injured. Although the faulty overhead maintenance work was the initiating factor, the high death toll was aggravated by use of highly flammable materials and poor design conforming to low wartime standards. To save the cost of glass, the windows were too small to escape from and there was no through passage along the length of the train. Finally, the electrically operated doors could not be opened when the power had been cut.

Train fire at Sakuragicho Station in Yokohama caused by sparks from overhead catenary during maintenance (24 April 1951) (*JNR CPH*)

## Accidents due to Rapid Postwar Recovery and Modernization

*Collision due to misread signal and insufficient braking power on 15 October 1956*

This accident occurred when Rokken Station in Mie Prefecture on the Sangu Line received a special order to stop a double-headed passenger train on the down line bound for Toba that usually passed through the station. The station departure signal was showing the stop aspect but the passing signal at the station entry was showing the proceed with caution aspect. The train driver was in the habit of passing through the station so he proceeded without confirming the passing signal aspect but then suddenly realized that the station departure signal was showing the stop aspect. He applied the emergency brakes but could not stop in time and entered the safety siding at 27 km/h where the two heavy locos

Multiple collision on Joban Line near Mikawashima Station, Tokyo (3 May 1962) (*JNR CPH*)

derailed and overturned. The following three passenger carriages also overturned, blocking the up line. Then an arriving up train collided with the derailed train, killing 40 people and injuring 96 others.

Although the accident was primarily due to the train driver misreading the passing signal, the sudden increase in train frequencies sometimes necessitated this type of change in scheduled passing stations and the manual handling of the signals and interlocking to deal with these sudden changes was troublesome, resulting in an increased number of signal mistakes. Clearly, automatic signalling was needed. In addition, the increase in the number of long trains required double-heading with heavy locomotives to haul them, necessitating upgrades to more powerful air brakes.

### *Level-crossing accident on 29 August 1961*

In this accident, a train on the down line between Niitsu and Kyogase on the Uetsu main line in Niigata Prefecture hit an articulated truck on a level crossing and dragged it 25 m down the track to hit a 61-m trussed girder at the front of the River Agano railway bridge where it derailed and fell into the river, killing two people and injuring many others. The accident was mainly due to the negligence of the truck driver but the sudden increase in the number of motor vehicles on Japan's roads during this period of high economic growth resulted in many more level-crossing accidents. The problem was gradually solved by installing level-crossing warning equipment and promoting grade separation.

### *Multiple train collision at Mikawashima on 3 May 1962*

This catastrophic accident occurred in Tokyo as a freight train from Tabata Station on the down Joban freight line was climbing a 10 per mill grade at 35 km/h to join the main line at Mikawashima Station. The departure signal on the freight line was showing the stop aspect to allow an EMU passenger train on the down main passenger line to leave the station. But the driver of the freight train ignored the signal and broke through onto the safety siding where the loco and first tanker wagon derailed to block the down passenger line. The EMU departed on the down line and struck the derailed freighter to derail and block the up line. Finally, an EMU composed of six carriages arrived on the up line to collide with the two derailed trains, resulting in a total of 160 lost lives and 296 injuries.

The ignoring of the departure signal by the driver of the freight train started this accident sequence but the Mikawashima stationmaster failed to notify Minami Senju Station up the line as soon as it happened. Moreover, insufficient training had been given in use of the signal fusee, which was supposed to prevent this type of multiple sequential accident.

The report into this accident came to the following conclusions.

The Mikawashima–Minami Senju section had not been upgraded at all for 30 years before the accident. Previously, it was handling 80 trains in both directions each day but by 1962, this figure had increased threefold to 240 trains due to the increasing population around the line. Clearly, the freight and passenger lines should have been separated to handle this high traffic density.

Moreover, there was a real need for a dedicated communications line to provide speedy relay of information between locomotives, EMUs and stations.

Engine drivers make human errors when reading signals and the frequency of such errors increases in direct proportion to increased train speeds and train frequencies. Such errors can be prevented by installation of ATS protective systems. These are all hardware-related problems but what about the 'software?'

When the EMU collided with the derailed freight train, the Mikawashima stationmaster first reported the accident to the Tokyo Operation Control Center but took no action to stop departure of the next EMU, resulting in the multiple collision. This happened because the rules had not been updated since the time when there were just a few daily operations. Technological advances had resulted in increased speeds and operations frequency but the safety-related laws and rules were out-of-date and the mismatch resulted in the accident.

The final recommendations of the accident report were to:

- Update the operations rules,
- Install ATS and train radio systems on all sections of the JNR network, and
- Separate the freight line from the passenger line on the section between Mikawashima and Minowa (signal box) where a large number of freight trains share the tracks with passenger trains.

These improvements have all now been completed.

### *Multiple collision at Tsurumi on 9 November 1963*

In this accident, the 43rd wagon of a long freight train travelling at 60 km/h on the down freight line of the triple double-tracked Tsurumi–Shin Koyasu (Yokohama) section of the Tokaido main line derailed and the following two wagons overturned to block the up passenger line. Within seconds, a 12-car EMU travelling to Tokyo arrived on the up line. The front three carriages of the EMU struck the derailed freight wagons and turned over on the right side. Another 12-car EMU was passing on the down line and its fourth and fifth carriages were hit by the overturning carriages of the other EMU. This multiple collision left 162 people dead and 120 injured.

A JNR accident investigation committee was immediately convened. The first question was why did the freight train derail? Its speed of 60 km/h was not unusual and no problems were found with the wheel flanges, axles, springs, couplers or air brakes. The track was also found to be OK. So what initiated the derailment? Tests were conducted for 5 years by the Railway Technology Research Institute (RTRI) on a test track using the same rails and rolling stock. They discovered that the combination of wheelset design and tyre profile, rail cross section and wear, and track geometry all played a role in the derailment.

Until this time, rolling stock and track design had followed traditional methods dating from the early days. In other words, static inspection was the mainstream.

However, static inspection methods were inadequate for guaranteeing safety considering the increased speeds and train frequencies associated with new technologies and electrification of main lines.

As a result, it was soon realized that new track inspection cars employing dynamic inspection methods and data collection were needed. All rules related to rolling stock, track, power and signalling systems as well as train operations were updated to meet modern demands.

Clearly, the failure of 'software' system to keep up with developments in railway hardware had lead to this major accident at Tsurumi and the loss of 162 lives.

In the Mikawashima accident, the operation rules were out of date; the first priority of the stationmaster should have been to prevent the multiple accident by stopping the other trains and then to report to the Operation Control Center. In the Tsurumi accident, reliance on out-of-date static analysis was insufficient to predict the dynamic combination of accident factors. This was the period just before the advent of today's modern railways based on information technology (IT), but these two accidents remain as valuable lessons for us today.

Multiple collision on Tokaido main line near Tsurumi Station (9 November 1963). The accident was due to a derailed freight train blocking several adjacent tracks. (*JNR CPH*)

Derailment experiments conducted by RTRI on test track using same rails and rolling stock (*JNR CPH*)

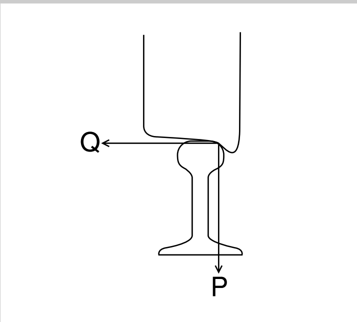
## Development of Shinkansen Technology

During this same period, the decision was taken to build the new high-speed 515-km Tokaido Shinkansen between Tokyo and Osaka and discussion started on how to assure safety after the start of operations.

The shinkansen was to be built exclusively for high-speed intercity passenger trains, with no mixed traffic of slower local trains and freight trains. To allow high speeds, sharp curves and steep gradients would be avoided and no level crossings were permitted. It was finally constructed with no trackside signals—a receiver on the head car detects a pulse frequency transmitted by the track circuit to display the speed instruction on a panel in front the driver. If the driver exceeds the speed indicated on the panel, the brakes are applied automatically. This signalling and automatic braking system is called Automatic Train Control (ATC). All traffic control operations are handled by the Central Traffic Control (CTC) centre at Tokyo Station.

The earlier tragic accidents at Mikawashima and Tsurumi were discussed at length and played a major part in discussions on the following technical aspects about how to assure safe operations at speeds around 300 km/h.

**Figure 1 Limits on Derailment Q/P Factor**




- Limits on derailment Q/P factor (Fig. 1)
- Tyre profile
- Rail profile
- Rail longitudinal irregularity limits
- Rail vertical irregularity limits
- Track gauge irregularity limits
- Track flatness irregularity limits
- Adhesion limits (wheelslip and slide prevention)
- Catenary wire and pantograph separation
- In-carriage and external running noise reduction
- R&D into human performance limits at high speeds of operations and maintenance staff
- Natural-disaster countermeasures (typhoons, earthquakes and flooding)

Research was conducted into these subjects between 1962–63 to formulate the basis for the shinkansen design and the results were incorporated as follows into Law 111 (1964) to ensure safe operation of shinkansen with a maximum penalty of 5 years imprisonment with hard labour for breaking the law.

- Damaging safety-related equipment shall be prohibited.
- Entrance to tracks and disposal of objects thereon shall be prohibited.
- No objects shall be thrown onto running trains.

Even with such extensive precautions, there still were some very serious problems that were not anticipated at the planning stage.

### Snow problems

One unexpected problem started with a heavy snowfall at Sekigahara (between Nagoya and Kyoto) in December 1965. Shinkansen trains running through snowfall at very high speeds blow up the snow on the track. The blown snow sticks to the underfloor equipment and freezes rapidly into ice. When the train enters a warmer region, the frozen ice thaws and drops at high speed from the train causing the ballast to fly up and seriously damage the underfloor equipment. There was no immediate solution other than reducing speeds to 70 km/h in snow. Later, water sprinklers were installed along the track in order to melt the snow, but speeds in snow are still restricted even today (although not as slow as 70 km/h in most cases), because excess water sprinkling can damage soil embankments. Drawing lessons from this, the Joetsu Shinkansen, which runs through a very snowy region north of Tokyo, was built entirely on concrete viaducts and large amounts of warm water are sprinkled during snowfall.

### Near misses

As the following examples illustrate, there were also some serious incidents that may have led to fatal disasters, although they were narrowly avoided.

*Wheel axle breakage on Tokaido Shinkansen on 25 April 1966*

The train guard (conductor) of a Tokyo-bound Hikari No. 42 train noticed unusual shaking of the last car, which was followed by a loud crash and sparks from under the floor. On his urgent report, the driver stopped the train near Toyohashi Station. JNR's emergency inspection revealed that a wheel axle of the last car was badly cracked. Thanks to the design of spring clip supporting the gearbox, the train narrowly escaped derailment and other serious consequences. The breakage of the axle was caused by faulty grinding at the manufacturing plant. JNR immediately tightened axle inspection using ultrasound and fluorescence technologies and no such incident has occurred since then.

*Shinkansen train overrun and derailment on 21 February 1973*

An out-of-service shinkansen train was departing from Torikai Train Depot for Shin Osaka Station. When approaching the entry points at the main line, the ATC cab signal showed 'Zero', ordering the train to stop to allow another shinkansen train on the main line to pass first. However, the train failed to stop in time and the head car ended on the main line after breaking through the closed points. The driver and dispatcher at the CTC centre were both confused by the unexpected incident and tried to reverse the train back off the main line, leading to a complete derailment due to the broken points. Although the route of the approaching train was blocked, it was far enough away for the ATC system to stop it in time, narrowly avoiding a disaster. JNR's emergency investigation revealed that wear-prevention oil on the depot departure line caused the train to skid and overrun.

*ATC Signal failure on 12 September 1974*

The ATC cab signal of a Tokyo-bound Kodama shinkansen train suddenly showed 'Zero' (stop) near Shinagawa Train Depot (Tokyo) and the brakes were applied automatically. After the train came to a complete stop, the cab signal showed '30' (advance at 30 km/h), so the driver edged ahead while watching the track. Luckily he noticed that an ahead point was closed. He immediately reported to the CTC centre. A closed point should have been technically impossible because it contradicts the ATC signalling principle. If the route is not open for the train, the cab signal must show 'Zero.' Moreover, the system is designed to show 'Zero' by default if the ATC fails or malfunctions. JNR organized an emergency investigation team, which finally found that a high-power electric device next to the ATC ground controller had induced a current in the ATC signal circuit with the same frequency as for the '30' cab signal. To prevent similar problems, JNR immediately separated all power equipment from the vicinity of ATC devices.

## Synthesis of New Technologies

Modern railways could be described as an equipment-based industry rather than the labour-intensive industry of the past, and the shinkansen is a completely different system from conventional railways, bringing together various important technologies such as civil, construction, mechanical, electrical and electronics engineering, as well as chemistry, metallurgy, meteorology, human engineering, etc. Today's widespread adoption of IT has facilitated centralized data handling by the Operation Control Center from where operators control dispatch of trains, schedule maintenance work, monitor power supplies and communications, etc., as part of a complex man-machine interface. The success of this system is evidenced by the 35 years of shinkansen operations since 1 October 1964 carrying more than 60 billion passengers (including all the operating shinkansen lines totalling 2150 km) without a single operations fatality.

Safety is best achieved by learning from past accidents, introduction of new technology and establishing balanced systems. In addition, railway staff must follow the operation rules and work according to manuals and check lists. But there is no way to guard completely against human error and forgetfulness. One way to reduce human error is to insist on working according to checklists, etc. Management of safety and maintenance can be assured by using computer databases to monitor collected fault and failure data and these types of systems have been used to create the basis of accident-free shinkansen operations.

Shinkansen run at maximum design speeds of about 300 km/h at headways of as little as 3 minutes based on a variety of technologies and a deep man-machine interface.

## Conclusion

Unlike other transport modes, railways are a one-dimensional mode that is relatively easy to systematize. The first railway accidents were largely due to natural disasters but later accidents were more commonly associated with signalling-related mistakes and errors by train crews and station staff. More recent accidents were associated with increased operating speeds and higher train frequencies exceeding the human ability to respond appropriately.

Railways in the 21st century have incorporated IT as a fundamental technology in progressing towards becoming an almost completely safe transport mode but we should learn the lesson that accidents reflect the technologies of the day. Human factors will always play a part in safety and we should remain cautious about placing too much faith in technology. ■

**Masao Saito**

Mr Saito studied mechanical engineering at Waseda University. He joined the JNR in 1946. He was responsible for train operations on the Tokaido Shinkansen for a long period after its inauguration. He also served as Director General of JNR's Labour Science Research Institute. He left JNR in 1972, and joined the NEC Group, the Japanese electronics giant. As President and then Chairman of NEC Railway Communication Engineering Co., he travelled extensively and visited almost every railway in the world. Since 1988, he has been Executive Consultant for Railway Systems Engineering of the United Nations Development Program. He wrote about Asian high-speed rail projects for *JRTR* 3.