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Application and effectiveness of assurance technology for autonomous decentralized railway signalling systems

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Abstract

This paper discusses assurance technology and its application in autonomous decentralized railway signalling systems. It is known as a technology utilized in various situations for the replacement of one system with another without stopping the system operation of these systems.

East Japan Railway Company adopted assurance technology on the introduction of D-ATC (Digital Automatic Train Control system) to the train control system operating on the busiest lines of the Tokyo metropolitan area. It was not only able to contribute to step-by-step construction (migration) and to improving the reliability of the D-ATC, but also effective in the enhancement of functionality of the railway signalling system which directly relates to railway business.
Keywords: assurance, autonomous decentralize, train control, ATC, reliability.

1 Introduction

In recent years, systems require not only safety and reliability but also flexibility for upgrading in accordance with the needs of society and users. Railway signalling systems require high levels of safety and reliability. At the same time, it is ever more necessary to continue stable operation while dealing with various customer needs, such as through service over multiple lines, establishment of new stations and the change of the train stop pattern of stations. Assurance technology [1, 2] enables us to cope with these demands, and it should be regarded as important as RAMS to railway signalling.

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D-ATC (Digital Automatic Train Control system) is deployed on the Yamanote Line and the Keihin-Tohoku Line i.e. the busiest lines in the Tokyo metropolitan area with 6.5 million passengers a day (figure1). It was introduced as an autonomous decentralized [3, 4] train control system to replace the existing analogue ATC system for the first time in Japan. To reduce the congestion rate during peak periods, a 10-second reduction of the train headway from 2 minutes 30 seconds to 2 minutes 20 seconds was required.

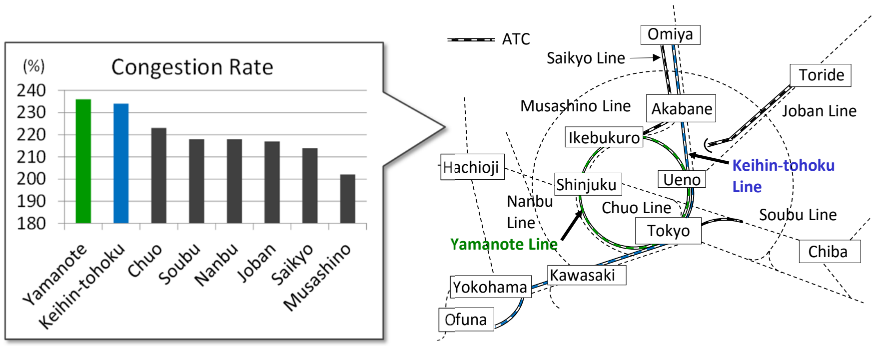

Figure 1: Railway lines in Tokyo metropolitan area and the congestion rates.

The installation involved changes of the arrangement of block sections, the parameter change of existing interlocking devices and replacement from the old to the new ATC system over the entire line. In addition, there were many tests at the site to be carried out before operation and it was impossible to finish the tests during only the short night interval time between train operations. Therefore, the coexistence technique based on the assurance technology was utilized and coexistence of the conventional ATC system in the D-ATC was enabled.

This paper shows the outline of the assurance technology and its actual application to railway signalling systems. In addition, the coexistence technique based on assurance technology adopted in the D-ATC system integration test is discussed. It also clarifies that assurance technology is applicable to a wide variety of railway signalling systems which directly relate to railway business, and that it is effective in the enhancement of the functionality of railway signalling.

2 The D-ATC and necessity of introducing adaptability technology

2.1 Outline of the D-ATC

D-ATC is an on-board-centred train protection system using information transmission through track circuits [5, 6]. As shown in figure 2, the D-ATC wayside devices transmit the MSK modulated 64-bit message of the block section where the train has to stop, and the on-board device generates continuous service braking curves based on the information from the ground as well as the on-board database of line profiles. Train positions are calculated by on-board tachometers.

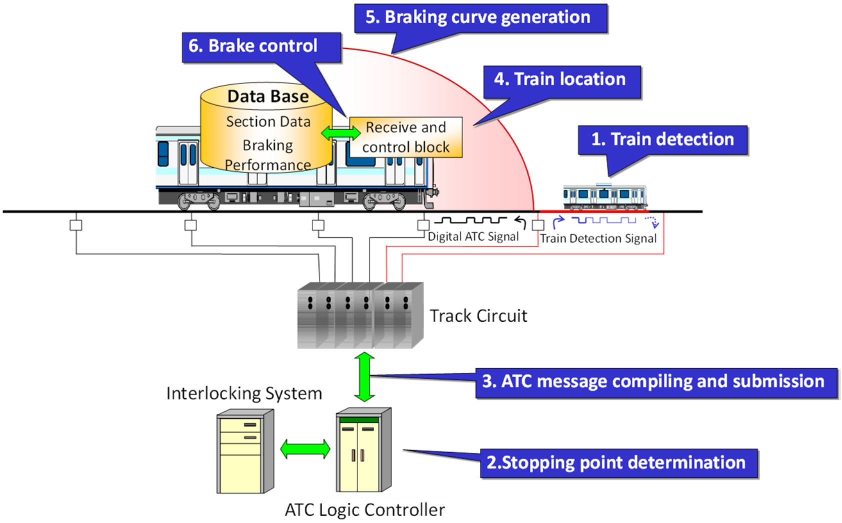

Figure 2: Outline of the D-ATC.

The functionalities of the D-ATC are summarised as follows:

(1) Train detection
The ATC logic controller transmits train detection signals to all the track circuits and detects trains according to the received signals.

(2) Determining stopping points
The ATC logic controller determines the subsequent trains' stopping points based on the detection of the preceding trains.

(3) Compilation and transmission of the ATC messages
The ATC logic controller compiles ATC messages of the stopping points and transmits them through track circuits.

(4) Train locating
Each train's on-board equipment locates its train by counting the pulses of the tachometer.

(5) Braking curves generation
The on-board equipment has a database (DB) of line profiles including route types and permitted maximum speeds. It generates continuous service braking curves based on the DB and the stopping point derived from the location of preceding trains, as well as that of the train concerned.

(6) Applying brakes
The on-board equipment compares the actual train speed and the speed defined by the generated braking curve. If the train speed exceeds the braking curve, the on-board equipment automatically applies the brakes.

As well as the other ATC systems, D-ATC has interfaces with track circuits and transmits ATC messages through it. D-ATC also has interfaces with interlocking systems which control routes and point machines in the stations.

2.2 Necessity of introducing adaptability technology for the D-ATC construction

As well as enabling us to reduce headways, D-ATC offers great advantages in train operations, compared to the conventional ATC which adopts step-wise speed control.

However, the total distance of the Yamanote Line and the Keihin-tohoku Line is approximately 120 km and therefore introducing D-ATC to the entire line requires an extremely long period. We, as a railway operator, faced the needs to shorten the headway immediately and at the same time to reduce the risks of trouble by reducing the construction work involved in switching from the old to the new system. We divided the entire line into 3 sections and implemented the step-by-step renewal for each section (figure 3).

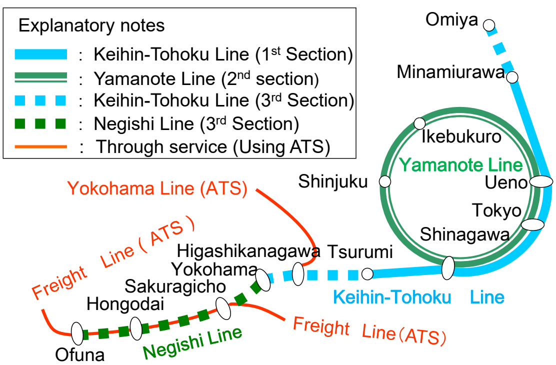

Figure 3: Deployment of D-ATC

For the step-by-step construction of the D-ATC system, application of adaptability technology [7] of assurance technology, described below, was considered.

3 Adaptability technology of assurance technology

Adaptability technology of assurance technology is necessary for step-by-step renewal of the system without stopping the operation as well as for flexibly coping with the system's development and expansion. Adaptability technology has two aspects (Table 1).

Table 1: Concept of adaptability technology.

Adaptability technology	Concept
Temporal system transition (development)	Within the section of system A, the system A is replaced with system A' without stopping the system operation.
Spatial system transition (expansion)	Within the section where system A and A' operate, the area of system A' is expanded without stopping the system operation.

The concepts are shown in figure 4 and 5.

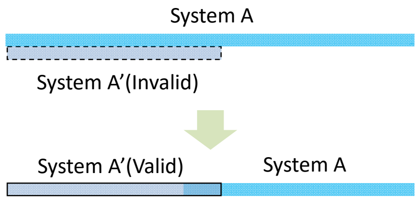

Figure 4: Temporal system transition.

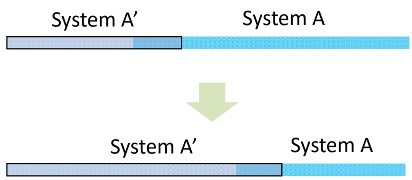

Figure 5: Spatial system transition.

In figures 4 and 5, the adaptability technology can be applied to the step-by-step construction of D-ATC by considering the conventional ATC as System A and the D-ATC as System A'.

In the subsequent sections, issues in applying the adaptability technology are considered.

4 Problems in actual application of adaptability technology for D-ATC

4.1 Problem on temporal system transition

The total length of the Yamanote Line and the Keihin-tohoku Line is approximately 120 km. And the number of train sets on those lines is more than 150 sets. In order to introduce D-ATC, we need to change over the system for about 40 km of the line and for more than 50 train sets within the 3 hours of the night interval time, considering we divided the construction into 3 sections.

4.2 Problem on spatial system transition

As seen in figure 3, the 3rd section includes Negishi Line, where freight trains and some extra passenger trains run with another signalling system called ATS. Therefore, mixed system operation is required in this section.

In addition, besides the boundary between conventional ATC and D-ATC, the system boundary between D-ATC and ATS must be established.

4.3 Concept for solving the problems

To migrate the system temporally and spatially without influencing the conventional ATC's operation, the "on-board autonomous decentralized control technology", which is realized by D-ATC, is utilized.

5 Element technology for solving problems

The element of the technology to construct the changeover logic to the on-board autonomous decentralized control technology is described below.
In D-ATC system, an on-board computer generates the brake curve according to the limited movement authority transmitted from the wayside device and autonomously applies the brakes based on its location recognition, while the conventional ATC system transmits the speed signal from wayside devices (figure 6).

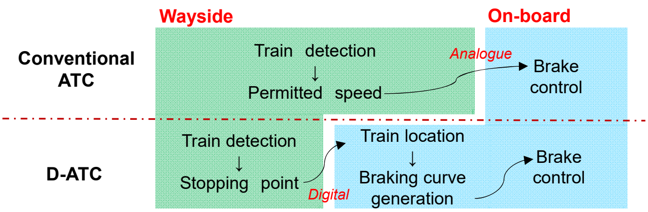

Figure 6: Functional allocation between wayside and on-board.

The technological elements required to realize the functionality are "digital transmission between wayside and on-board" and "location recognition". Those technologies are realised in D-ATC, enabling the "on-board autonomous decentralized control" The on-board device can autonomously select its appropriate behaviour according to the situation.

5.1 Digital transmission between wayside devices and on-board devices

The appropriate transmission speed and frequency bands are required to ensure necessary data size for transmission between wayside device and on-board devices. At first glance, utilization of high frequency to obtain a high data transmission rate seems desirable. At the same time, the influence of noise from existing equipment needs to be avoided to assure accurate demodulation.

There are various limiting factors contrary to these requirements. As a distributed constant circuit, rails have a large component of "L" and attenuation of high frequency transmission is large. In addition, the variance of leakage conductance according to weather conditions is not desirable for securing a constant reception level at the on-board device. Therefore, using low frequency with the necessary bandwidth is the best choice for actual application.

Moreover, various electrical signals such as conventional ATC signals, ripple noise from return current or VVVF inverter noise from the train coexist on the rails. This fact dramatically limits the appropriate frequency band.

Two frequency bands are needed for uplink and downlink. By adopting MSK (Minimum Shift Keying) modulation, the necessary frequency bandwidth is minimized and frequency use efficiency is maximized.

Considering all the viewpoints above, D-ATC signal was designed as approximately 50 mA to ensure the S/N ratio of 13 dB against the noise of 10 mA, and as 11.9 kHz and 13.1 kHz to limit the bit error rate below $1.0x10^{-5}$ /h.

5.2 Train location recognition

Train location recognition is performed with a tachometer mounted on a bogie. The tachometer converts the rotation of the wheel to distance, so it needs to recognize the wheel dimension correctly. Otherwise, error accumulates along the train run.

In addition, if the wheel slides while brakes are being applied, a large error in the location recognition may occur. Moreover, the tachometer has a characteristic of having large error at very low speeds. Taking these issues into account, we established the location recognition function to solve them as follows.

During the maintenance work, the wheel diameter is accurately measured and input to the system to minimize the error. This setting is reconfirmed by having the train run on the test track with two balises. Wheels wear in the train run and become smaller due to friction, but this is not a problem because the recognized position becomes far side, which is the safer state.

To avoid accumulation of location recognition error (approximately 0.2%), distance is calculated by multiplying measured distance by 1.002 and at the same time error correction balises are installed every 1 km between stations.

To avoid slide during application of the brakes, the tachometer is installed on an axle with weaker brakes. However, it is difficult to avoid slide completely, so the on-board computer judges slide by detecting deceleration above a certain level, it performs an error correction to the safe side.

Especially in stations, where trains need to stop accurately, balises are installed at shorter intervals (approximately 30 meters apart) in order to perform error correction more frequently.

To deal with the tachometer's error at very low speeds, we set up a specification such that error correction to the safe side is performed whenever the train stops or begin to move.

6 Application of adaptability technology to D-ATC

As explained above, the on-board autonomous decentralized control is realized. The actual application of adaptability technology based on this technique is described below.

During the construction period, signals from conventional ATC and D-ATC must coexist. Therefore, on-board computers are set to select the D-ATC signal if they detect both signals. Based on this function, we constructed the logic.

6.1 Application of temporal system transition

Figure 7 represents the concept of temporal system transition of D-ATC.

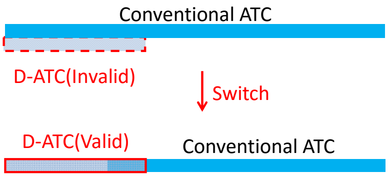

Figure 7: Temporal system transition of D-ATC.

To perform temporal system transition, the D-ATC function needs to be activated on many on-board devices at the same time within the limited night interval time. Utilizing the function that on-board devices preferentially select D-ATC signal, we solved this issue by setting the "valid or invalid bit" within the D-ATC message before beginning to use the system. When the "invalid bit" is set, all the on-board devices ignore the D-ATC signal. At the time of system transition, the bit is set to "valid" from the operation control center remotely, which results in activation of the D-ATC function of the on-board devices automatically (figure 8).

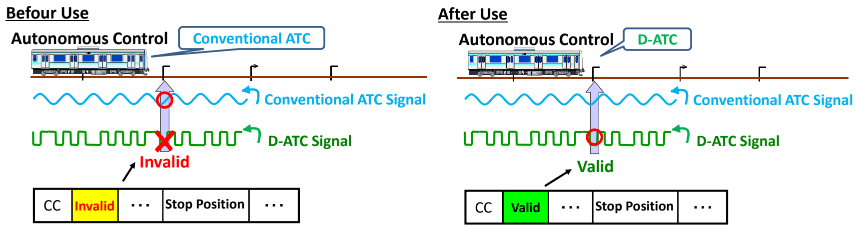

Figure 8: Temporal system transition in D-ATC.

6.2 Application of spatial system transition

In order to realize spatial system transition, continuous operation over multiple systems needs to be enabled. In our situation, two cases exist: system change between conventional ATC and D-ATC such as the changeover of 1st section and 2nd section, and system change between ATS and D-ATC such as the changeover of 3rd section (as shown in figure 9).

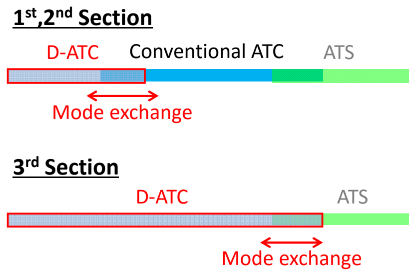

Figure 9: Spatial system transition of D-ATC.

6.2.1 Operation mode change between conventional ATC and D-ATC

(1) Changeover from conventional ATC to D-ATC

The changeover is enabled by superposing the D-ATC signal in addition to conventional ATC signal to the section of the entrance route of the boundary station. Balises for error correction are also installed on this section. The on-board computer performs the changeover based on both the condition of correct D-ATC signal detection and the location confirmation information from the balise (figure 10).

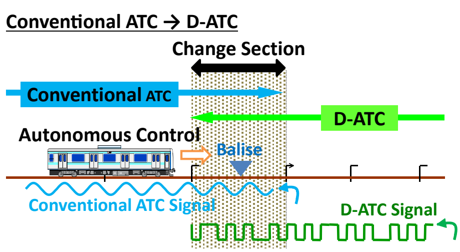

Figure 10: System transition from conventional ATC to D-ATC.

(2) Changeover from D-ATC to conventional ATC

To perform the changeover from D-ATC to conventional ATC, the function of the on-board device that preferentially selects D-ATC signal needs to be cancelled. Thus, we determined the specification for adding instructions for “changeover to conventional ATC” to the D-ATC signal at the changeover section, and for the change the operation mode of the on-board device to take place after stopping once (figure 11).

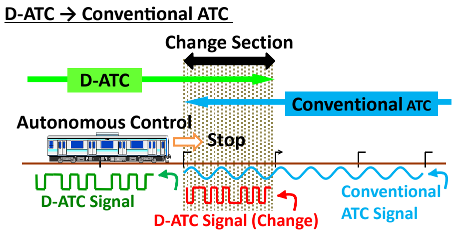

Figure 11: System transition from D-ATC to conventional ATC.

6.2.2 Operation mode change between ATS and D-ATC

The 3rd section includes the Negishi Line, where freight trains or other extra trains run with another signalling system called ATS. Therefore, mixed system operation is performed by installed signal lights and ATS in addition to the ATC.

On this mixed operation section, three types of trains run.

- Trains equipped with only D-ATC;
- Trains equipped with both D-ATC and ATS;
- Trains equipped with only ATS.

Among these, the trains equipped with both D-ATC and ATS need a changeover at the border station between D-ATC and ATS.

Figure 12 represents the case that an ATS mode train coming from B station changes to D-ATC mode at A station. There are only D-ATC trains on the main tracks, but the central passing track connects to freight line equipped with ATS. At A station, trains on the main track need to continue in D-ATC mode, but trains coming from the freight line and moving towards A station via B station need to change from “ATS mode” to “D-ATC mode” after stopping at A station. However, the wayside device at A station cannot distinguish which route the train passed at B station. For such cases, the conventional solution was to lay metallic cables from B station to A station, input the information of the route passed at B station into the device at A station, and send the changeover message to the on-board equipment after counting by timer to foreseen the train’s stopping time at A station. This solution was “wayside based” method and was common in conventional ATC.

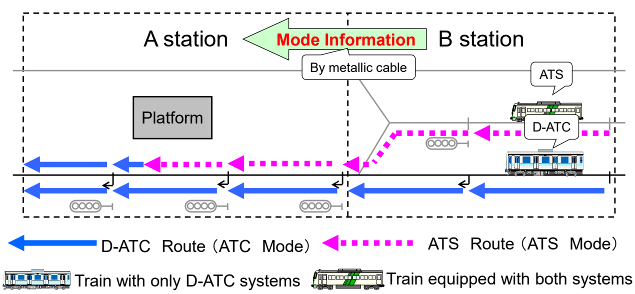

Figure 12: Conventional solution.

However, the D-ATC on-board device always recognizes its running route. Utilizing this feature, when the train comes from the central passing track at B station towards the main track at A station, the on-board computer makes an autonomous judgement based on its operation mode and running route and sets its own mode appropriately (figure 13).

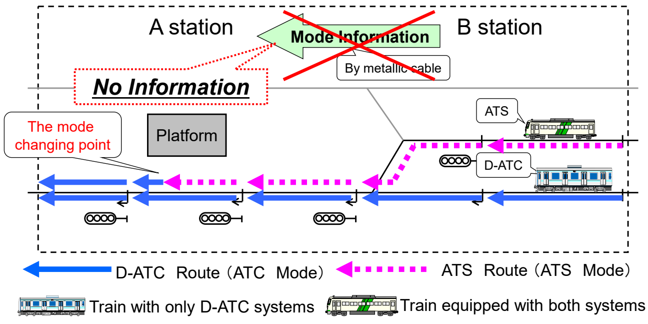

Figure 13: Solution by autonomous decentralized method.

Thanks to this method, changeover timing becomes constant and transmission of conditions between stations and the timer becomes unnecessary (table 2).

Table 2: Function reconstruction by on-board autonomous decentralized control.

	The Ground Requirement	The On-board Requirement	Timing
Ground Oriented	・Stopping Point ・Adjacent Station Information ・Clock Timer	・Signal Reception	Not Constant
On-board Oriented	・Stopping Point	・Signal Reception ・Mode Recognition ・Train Stop Detection	Constant

7 Conclusion

This paper described the outline of our D-ATC system (on-board autonomous decentralized control) and the actual application of adaptability technology.

To construct D-ATC system step-by-step, we adopted a method wherein the on-board device autonomously selects the appropriate system according to its location and the condition of its operation based on priority logic on inside the D-ATC among the three coexisting systems conventional ATC, D-ATC and ATS.

This method was realized by the on-board autonomous decentralized technology and it brought the following side benefit.

- The conventional ATC signal on the same section as D-ATC has no effect on the on-board device even after system transition to D-ATC. Therefore, we do not need to stop the conventional ATC signal at the transition date.
- The on-board device can change its operation mode from conventional ATC mode to D-ATC mode while running, so the changeover section can be selected wherever we like regardless of whether that is inside or outside a station.

Step-by-step construction was carried out and the first section was brought into practical use three years after the construction began (ten years for the entire line). Shortening the headway and greater speeds were realized in those sections.
In addition, by introducing spatial system transition, the operation mode change by human hand between conventional ATC and D-ATC or between ATS and D-ATC was eliminated. This eliminates human error. Moreover, as each on-board device was enabled to autonomously select the operation mode in the mixed operation section of D-ATC and ATS, wayside devices could be simplified by eliminating the condition transmission between adjacent station devices or timers to secure the mode change timing.

Adaptability technology of assurance technology is valid and feasible for various systems' step-by-step construction or mixed operation, and enables us to bring multiple various benefits like simple construction, improved reliability, cost reduction and other bonuses directly connected to railway business.

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