New ATC system with digital transmission and on-board intelligence

Masayuki Matsumoto, Yosuke Mizukami, Atsuhiko Hashimoto, Chikara Ikehira, Takashi Kawano, Keisuke Yagi,
2-2-2 Yoyogi, Shibuya-ku, Tokyo 151-8578, JAPAN,
Tel : +81-3-5334-1170, Fax: +81-3-5334-1117
E-mail : {m-matsumoto, mizukami, a-hashimoto}@head.jreast.co.jp, {c_ikehira, t_kawano, k_yagi}@teco.jreast.co.jp
East Japan Railway Company, JAPAN

Abstract

This paper introduces a new digital ATC (Automatic Train Control device) system developed by East Japan Railway Company (JR East).
In the current ATC, the central ATC logic device calculates permissive speed of each blocking section and controls speed of all trains. On the other hand, in the new digital ATC (D-ATC), the central logic device calculates the position at which each train should stop, and sends the information on that position to respective train. On each train, the on-board equipment calculates an appropriate braking pattern according to the information and controls its speed, that is, in the new system, the device on each train autonomously calculates permissive speed of each train. By this special feature, we can achieve ideal speed control of each train, making full use of its performance for acceleration and deceleration, which in turn allows high-density train operations.

Keywords: Automatic Train Control, Autonomous decentralized system, Automatic Train Protection, Digital transmission, On-board train location

1. Introduction

In urban areas, we have to conduct high-density transportation and keep it safe at the same time. Train operation can be approximately divided into transportation planning, transportation management, route control, and train control. JR East has been working on the systematization of these operations. The introduction of IROS (Integrated Railway Operation System) for transportation planning and ATOS (Autonomous decentralized Transport Operation control System) for transportation management & route control has greatly contributed to efficient transportation planning work and stable transportation. They have enabled the operators to restore the disrupted schedule of train operation in a short time. In the area of train control, automatic train control device (ATC) is still used for the Shinkansens and some lines in the Tokyo Metropolitan Area. However, since the ATC device is based on the technology that has been existing since the establishment of Shinkansen, it involves many problems such as an inability to increase the number of trains.

This paper describes safe operation in railway systems, and the problems and issues of the current ATC. Also, the primary objective of train control – “Controlling train intervals safely” – is presented. And then, D-ATC system – a new train control system based on a completely new concept that uses the latest information technology – is given.

2. Development of train control system in Japan

To keep safety of train service, high-level safety is required for train control system, and the system plays a very important role. Furthermore, by adopting train control system, it has become possible to increase the speed and frequency of trains. In other words, not only safety but also efficiency of operation has been expected for train control system, which has largely contributed to rationalization of our business.

2.1 Automatic train stop device

Trains are driven according to aspect of signal. It will be a fatal accident if driver pass over the stop signal because of bad weather or careless driving. The Automatic Train Stop device (ATS) alarms
the driver by ringing a bell or chime and displaying a red light when the train is approaching a stop
signal. If the driver does not confirm the situation within a set period (5 seconds), the brake is
automatically applied and the train will be stopped. However, once the driver presses the
confirmation button, he/she can still continue driving. In 1966, ATS device was introduced on all
national railway lines and is currently used on JR and many private railways. However, mistaken
handling has been the cause of accidents and is one of the disadvantages of ATS (Fig.1).

Fig.1 Principle of ATS

ATS-P was developed to eliminate this disadvantage of ATS. This device uses a transponder to
transmit digital information on the aspect of the signal, the distance to the next signal, and other
information from the ground to on-board, and to create a speed checking pattern on-board based on
those information. The train speed and this pattern are then compared by a computer and the brake is
applied if the speed of the train exceeds the pattern (Fig.2).

ATS-P was tested on the Kansai Line in 1980 and introduced on the Keiyo Line in 1988 and the
Chuo Line in 1989. Currently, it has spread to the main line sections of the Tokyo Metropolitan
Area, the Yamagata Shinkansen, and the Akita Shinkansen.
2.2 Automatic train control device
Since the failure to recognize the signal can lead to a serious accident, it was necessary to install device that display the permissive speed and apply braking automatically along with the alarm on high speed or frequency lines. This device is known as an automatic train control device (ATC).
Introduction of ATC has established safe operations even when drivers misread the signal aspect, and the level of safety has been raised compared to ATS with the point control system.
There are two types of ATC. The first one is the “Half-Overlap” system that controls the speed in stages by decelerating to the instructed speed in each speed section (Fig.3). The second one uses the “Closing-In” system in which exceeding the instructed speed is permitted as long as the train can be stopped before the stop signal aspect (Fig.4). The latter has the advantage of being able to reduce the train headway.
The current ATC device was first introduced to the Tokaido Shinkansen in 1964 and since then has been introduced to the Joban Line in 1971 and to the Yamanote and Keihin Tohoku Line in 1982. The system also began to be widely adopted on private railways from 1964.
3. Problems and issues of current ATC device
In the current ATC device, a signal device that indicates permissive speed is located in the driver’s cab on a train, and it continuously receives information on the permissive speed transmitted from ground equipment.
In the ATC device, the central ATC logic device takes charge of most of the train interval control, and on-board equipment only controls the braking of the train according to the instructions from the
central logic device.
The current ATC has the following problems, hindering the improvement of transportation:
(a) Since the current ATC is multi-level brake control designed as shown in Fig.3, too much brake application and release cannot be avoided. Thus, the train headway cannot be reduced.
(b) Even if the brake performance of rolling stock is improved, the speed limit is fixed for each blocking section. Thus, the transportation density cannot be improved.
(c) Although the train headway can be reduced with the Closing-In system, the reconstruction of ground equipment is costly.
(d) Sudden change of permissive speed at a section boundary induces bad driving operability for drivers and uncomfortable feelings for passengers.
(e) Most equipment is concentrated on one area, and many cables are connected to the respective track circuit from there. Thus, the facilities are heavy and expensive.

4. The digital transmission, on-board intelligence
4.1 Basic principle of the new train control system
The following is an analysis of the ideal form of ATC as a train control system. The only thing necessary to stop a train without running into the preceding train is to know “the distance to the position where the train must stop.” The essential information for this is “the accurate position of the train” and “the position at which the train should stop.” By reanalyzing the actual objective of ATC, the basic function of the new train control system emerges. In other words, the ground equipment should only transmit information on the position at which the train must stop and the train should recognize its own position and calculate the distance to the stopping point transmitted from the ground. The train then should take the roadway curves, gradients and other things into consideration and apply appropriate braking as needed. This is the principle of the D-ATC system that we have newly developed (Fig.6).

![Fig.6 Basic principle of the D-ATC system](image)

4.2 Characteristics of the D-ATC system
In this manner, the major difference between the D-ATC system and the current ATC is that the new system is an on-board intelligent system.
The following are the characteristics of the new system:
(a) High-density traffic is feasible as brakes are continuously applied up to the stop point using pattern control.
(b) The ground facilities can be slimmed down and made inexpensive due to the use of general
information equipment and a decentralized system.

(c) The system contains the flexibility of being able to shorten the train headway without changing
ground equipment due to improved rolling stock performance.
(d) Improved operability can be obtained by indicating the information on routes to the driver.

4.3 Information technology for the D-ATC system

(1) Digital transmission
The conventional analog ATC signal cannot include information on train control, such as limit of
moving authority (LMA), but it is difficult to develop other communication devices such as radios
because of many other problems. Furthermore, both new and conventional ATC device will have to
work concurrently for a long time, so it is necessary to reuse current devices. Therefore, the new
system uses the track circuit to transmit ATC signals like the current system and introduces digital
transmission. This improves the capacity and SNR of transmission through the track circuit.

(2) Network technology
Ground equipment device is placed at each station and they are connected with a fast digital network
in order to transmit information for train control. Ground equipment mainly consists of the central
ATC logic device, transmitter/receiver devices, and node devices. The ATC-LAN is the backbone
network that connects an ATC logic device and nodes. Transmitter/receiver devices are connected
with a node device through CAN (Controller Area Network). These networks have a duplex
configuration so that the system works even in case of some device failure.

(3) Autonomous decentralized technology
This system consists of decentralized devices that are connected with networks. These networks are
also connected with others through gateways (GW). One logic device communicates with another
one through the network in order to keep train control consistent with the whole system. An ATC
logic device autonomously controls the trains in the section that the device takes charge of, and also
cooperates with other devices. The on-board equipment also autonomously controls the speed,
recognizing the location of the train and calculating the braking pattern. This autonomous function
of the on-board equipment distinguishes the new ATC system from the conventional device.
These autonomous devices achieve safety by changing the state of the operation to a safe mode
(emergency braking, red signal, etc.) in case of communication failure between devices or reception
of inconsistent instruction.

(4) Detection technology of train location
In the D-ATC system, information of train location has a very important meaning. “GPS”, "Doppler
effect”, or “pulse count of the tachometer generator” is generally used to calculate the train location.
In this system, “pulse count of the tachometer generator” is adopted because it is easy to modify the
on-board device at a low cost.
However, Track circuit is adopted for detection of the preceding train, since an exact detection of the
position is required.

(5) Man-machine interface technology
Conventionally, there was no information for drivers on why the brake works, or where the train
should stop, so that an operation loss or a sudden braking is caused.
In the D-ATC system, information on the stop point and the brake control is sent to driving cab from
the receive and control equipment to support the driving visually or acoustically by display or sound.
By this system, the driver is able to know when to apply the brake in advance, so that moderate
braking or power-saving driving is achieved.
5. Subjects and solutions in deployment of D-ATC

5.1 Coexistence with the current ATC

There are various difficulties in introducing the D-ATC system on the lines with the current ATC device. The installation of the new system must not disturb the train operation with the current ATC device. It is impossible to replace all the equipment of the current system with the new system immediately and a long period is needed to replace entire the on-board equipment of trains with the new one. Therefore, the new and old ATC systems must work on the same line concurrently. The following are the solutions for introduction of the new system and for co-operation of both systems.

(a) During installation, the on-board equipment only processes the ATC signal of the current device and ignores the signal of the new system.

(b) In the new system, the non-insulated track circuit is adopted. This can co-exist with the current insulated track circuit by supplement of bypass-bond devices that let the signal of a particular frequency for the new system pass through. This configuration allows division of the track circuits independently of the current system.

(c) After beginning operation with the new system, the train equipped with new on-board equipment should receive and process both the new and current ATC signals on the border section of both systems. Each signal of the system must not disturb operation of another system. The modulation method and the frequency of both the ATC signal and the train detection signal is determined so that the signals of both systems do not disturb operation of another system.

(d) New on-board equipment for the new system processes the signal with digital signal processor (DSP) so that it can also process the signal of the current system. When the train passes the border section of both the new and old systems, the on-board equipment recognizes the change of ATC signal type. It can automatically change the process routine to the appropriate system and continues train operation without interruption.

<table>
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<th>Technology</th>
<th>Application</th>
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| Digital transmission     | • ground device → on-board device  
                          | (64bit, every 320msec)  
                          | train control information (stopping point)  
                          | • train detect (16bit, every 160msec)  
                          | digital signal processing (ground device and on-board device) |
| Network technology       | • on the ground  
                          | ATC-LAN (10Mbps)  
                          | • system connection with ATOS |
| Autonomous Decentralized technology | • system on the ground  
                                      | • system on-board |
| Position detection technology | • train position recognition  
                                    | calculation by tachometer generator  
                                    | • train detection  
                                    | track circuit |
| Man-machine interface    | • train operation support information to the driver |

*Tab.1 Information technology of the D-ATC system*
5.2 Cooperation with other systems
We have ATOS as a system relevant to D-ATC. In stations with interlocking systems, the D-ATC system creates digital telegram based on route setting information or track circuit information from ATOS. On the other hand, track circuit and train approach information between stations is transmitted to ATOS from D-ATC. Thus, it is necessary to establish both the interface technique and the method of replacement.

5.3 Safety and Reliability
In the D-ATC system, triple system composition (2 out of 3) is adopted for ground equipment. On the other hand, dual system is adopted for on-board equipment. Therefore, a measure of safety has been improved and a fatal failure rate of the entire system has been decreased to $10^{-12}$ (1/h). As for the ground equipment, higher availability is achieved compared to the current ATC device. Furthermore, as for the on-board equipment, necessary measure of reliability is achieved by hardware miniaturization (curtailment of the number of parts).

6. Construction of D-ATC
6.1 Configuration of the D-ATC system
The configuration of the new train control system based on the above concept is as follows:
The ground device and network equipment shall all be given a duplex configuration in order to guarantee reliability. Furthermore, the control logic device, which judges the stop position from information concerning the presence of other trains on the line, combined with ATOS, consists of a failsafe triplex majority processing system, as it handles vital information. In addition, a newly developed special interface lies between ATOS and D-ATC, synchronizing the route and train control.
On the other hand, there is no need for transmitter/receiver device that handles non-vital data and only sends or receives digital signals with track circuits to be a failsafe device, and as a result, the overall system configuration can be slimmed down. These devices are connected via a 10Mbps optical network called an ATC-LAN. The on-board device receives signals from the ground using an on-board antenna like those used in the current ATC, and the receive and control equipment processes the information on brake control.
It must have a duplex configuration for the failsafe processing. In addition, on-board database also has a duplex configuration.
Both the ground device and the on-board device are configured as autonomous decentralized system and each of them can operate autonomously.

Fig. 8 System configuration of the D-ATC system

6.2 The functional outline of D-ATC
(1) Train detection
For the D-ATC system, non-insulated track circuit is adopted. The initial cost of this kind of track circuit is relatively low. This is because an insulation part and a big transformer for the train traction current bypass should not be necessary at the boundary of track circuit sections. A central ATC logic device transmits the train detection signal to all the track circuits and receives the level of received signal power, and then detects the train in a 160ms cycle.

(2) LMA (limit of moving authority) calculation
The logical device calculates the LMA of the train from the preceding train location and route information from an interlocking device, and then generates an ATC message, sends it to the transmitter. The transmitter modulates the message to an ATC signal (64bit, MSK: minimum shift keying) and transmits it to a track circuit in a 320ms cycle.

(3) Train position recognition
In the on-board system, the train position is always recognized by counting the pulse of the tachometer generator. However, compensation is needed in order to prevent accumulation of the small errors of the tachometer generator counts, and is achieved by installing transponders, with actual successful results in railway systems, to provide the information on exact train position at a fixed interval.

(4) Braking pattern generation
On-board equipment has a database (DB) of route patterns and permissive speed of the line. The on-board equipment searches the DB for braking pattern based on the location of the train and the
preceding train, and then generates the braking pattern.

(5) Braking control
On-board equipment compares the train speed and the current permissive speed based on the calculated braking pattern. If the speed exceeds the pattern, it automatically controls the brake device. The braking intensity is moderate at the beginning and at the end of braking, and becomes stronger in between, for passenger’s comfort.

(6) Support for drivers
The on-board equipment displays preliminary announcement of approaching the pattern before a brake works. In addition, opening-of-traffic situation of the route is displayed on the monitor, thus improving the operability for drivers.

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6.3 Effects of the new train control system
Consequently, the cost of the new train control system is less than that of the current ATC and has also reduced the train headway to two minutes from two minutes and thirty seconds of the current ATC sections. It is also expected that construction costs can be lowered by twenty percent compared to traditional methods.

7. Future Direction
It was decided to first introduce D-ATC system between Minami Urawa and Tsurumi on the Keihin Tohoku Line and its ground construction began in June last year. Construction will continue from now on and the new train control system will be in effect in 2003. Further plans will be expanded over the rest of the Keihin Tohoku Line and the Yamanote Line. This will alleviate traffic congestion on those lines.

JR East plans to introduce the system on the Hachinohe extension of the Shinkansen and also on replacement of the aged ATC on the Tohoku and Joetsu Shinkansens. Furthermore, the ideal form of interval control, in which trains know each other’s positions through wireless communications, will also be available. JR East is currently developing this type of a train control system that uses wireless communications, called “ATACS.”
8. Conclusion
We have described the applications of information technology by JR East, particularly focusing on the train control system. Both “the development of information and communication technology” and “the increasing transport needs” have boosted the progress of train control systems in Japan. We have emphasized the history of this development and its problems in this paper. The construction of a completely new train control system for high-density line was also described. The construction is being advanced at present with this system, aiming to start the operation in 2003.

References