Development and Maintenance of Class 395 High-speed Train for UK High Speed 1

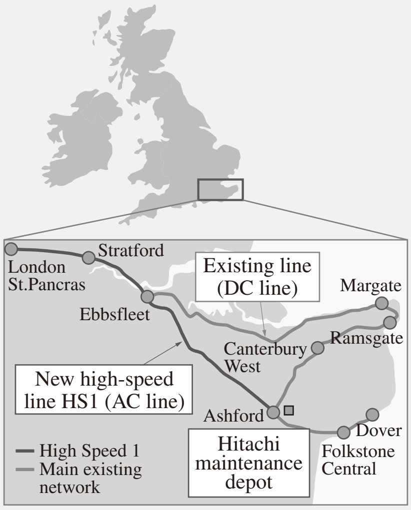
Toshihiko Mochida
Naoaki Yamamoto
Kenjiro Goda
Takashi Matsushita
Takashi Kamei

OVERVIEW: Hitachi supplied 174 cars to consist of 29 train sets for the Class 395 universal AC/DC high-speed trains able to transfer directly between the UK's existing network and High Speed 1, the country's first dedicated high-speed railway line. The Class 395 was developed by applying technologies for lighter weight and higher speed developed in Japan to the UK railway system based on the A-train concept which features a lightweight aluminum carbody and self-supporting interior module. Hitachi is also responsible for conducting operating trials to verify the reliability and ride comfort of the trains and for providing maintenance services after the trains start operation. The trains, which formally commenced commercial operation in December 2009, are helping to increase the speed of domestic services in Southeast England and it is anticipated that they will have an important role in transporting visitors between venues during the London 2012 Olympic Games.

INTRODUCTION

HIGH Speed 1 (HS1) is a new 109-km high-speed railway line linking London to the Channel Tunnel [prior to completion of the whole link, the line was known as the CTRL (Channel Tunnel Rail Link)]. Construction of the line, which is the first dedicated high-speed railway in the UK, commenced in 1998 and operation along its full length started in 2007. This cut 40 minutes off the travel time along this stretch of line for the Eurostar international train which previously ran on the UK's existing railway network. Hitachi supplied the new Class 395 high-speed train to be able to run on both HS1 and the existing network as part of a project to improve domestic services on adjacent track as well as make more effective use of the new line (see Fig. 1).

As the contract with Hitachi's UK customer included maintenance services, it was important that



DC: direct current HS1: High Speed 1 AC: alternating current

Fig. 1—Class 395 High-speed Train for UK High Speed 1 and Route Map.
Based on the A-train concept it developed in Japan, Hitachi developed and supplied high-speed trains able to transfer directly between the UK's existing network and the new high-speed line High Speed 1 linking London and Dover. The service, which formally commenced commercial operation in December 2009, is helping increase the speed of domestic services in Southeast England.

the trains comply with the customer's requirements and local standards while also taking account of maintenance and LCC (life cycle cost) considerations from the train's design stages.

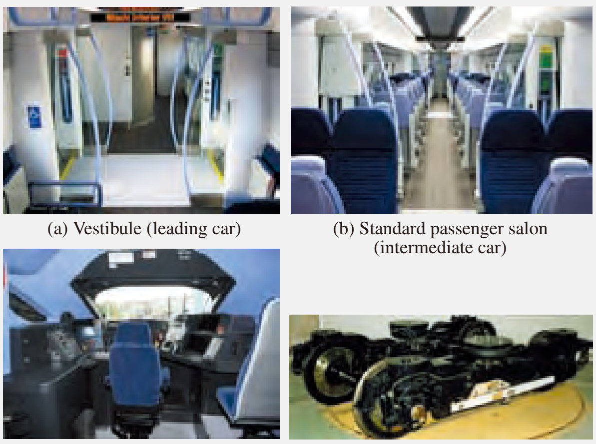
This article provides an overview of the Class 395 high-speed train for the HS1 in the UK and describes its distinctive technologies and the maintenance service provided from a new maintenance depot built specifically for the train.

EXTERIOR AND INTERIOR OVERVIEW OF CLASS 395

Design

The "one motion form" design with its smooth nose-shape and low air resistance not only creates an image for the front-end of the train that is ideal for a high-speed train, it also reduces train resistance and noise. The exterior color, which was specified by the railway operator, has a dark-blue base with yellow used to highlight the front end of the train (see Fig. 1).

White is the main color used for the interior walls and ceilings. The aisle width, lighting, and arrangement of interior equipment follow a universal design that complies with the UK's RVAR (Rail Vehicle Accessibility Regulations). The seat layout is based on two-person seats in the standard passenger compartments with single-person tip-up seats fitted in the wheelchair space in the leading car. The trains have open vestibules that are not segregated from the passenger compartments and these are fitted with draught screens that act as a windbreak (see Fig. 2).



(a) Vestibule (leading car) (b) Standard passenger salon (intermediate car)

(c) Driving cab (d) Bogie

Fig. 2—Vestibule, Passenger Salon, Driving Cab, and Bogie.
The open vestibules (a) are not segregated from the passenger salon and the seat layout is based on two-person seats (b). The driving cab was reviewed by train drivers for its ease-of-use and visibility and this feedback was incorporated into the design (c). The design of the bogies considered stability when traveling on the new high-speed line and cornering characteristics on the existing line (d).

TABLE 1. Key Rolling Stock Specifications
The main specifications of the Class 395 trains are shown.

Item	Specification
Class	UK Class 395
Trainset	6 cars (DPT1 + MS1 + MS2 + MS3 + MS4 + DPT2)
Number of passengers	Standard seating: 298, priority seating: 42
Electric system	AC 25 kV, DC 750 V
Gauge	1,435 mm
Maximum speed	225 km/h (AC overhead line), 160 km/h (DC third rail)
Acceleration	0.70 m/s^2
Deceleration	Normal: 0.90 m/s^2, emergency: 1.20 m/s^2
Gradient	25‰ (max.)
Brake control	Electrically operated air brake
Main converter	4 × IGBT converter/inverters + brake choppers per set
Main electric motors	16 × 210 kW sequential per set
Auxiliary power supply units	3 × 110 kVA per set (3-phase 400 V AC + 110 V DC)
Carbody	Double-skin aluminum structure
Bogies	Bolster-less bogies
Air conditioning	Heater-type heating, ventilation, and air-conditioning unit (with internal ventilation fan)

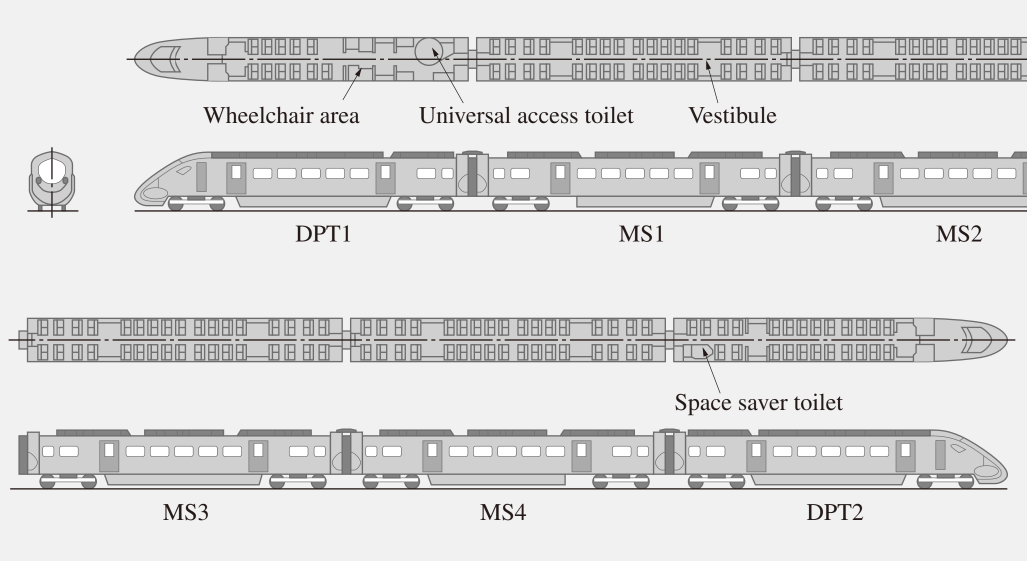
D: driving cab P: pantograph T: trailer car M: motor car S: standard car
IGBT: insulated gate bipolar transistor

Basic Specifications

Table 1 lists the main specifications and Fig. 3 shows a diagram of the train formation. The trainsets consist of six cars per trainset and both leading cars are fitted with automatic couplings with front hatches so that up to two trainsets can be coupled to allow operation with 12 cars per train. As the trainsets may be coupled or uncoupled at intermediate stations when in operation, the automatic couplings are designed to take no more than one minute to complete coupling or uncoupling.

The carbody is made of aluminum alloy and the sides, roof, and floor have a double-skin structure formed from hollow thin-wall extrusions. Further, use of FSW (friction stir welding) for the welds achieves an exterior that is light, has high strength, and minimal strain[1]. The trains also travel at speeds exceeding 200 km/h and the cars are made airtight.

The bogies are bolster-less and, in addition to being designed for stability when traveling on the new high-speed line and for curving performance on the existing



Fittings/Number of units	
Standard seats	298
Priority seats	42
Capacity	340
Tip-up seats	12
Universal access toilet	1
Space saver toilet	1
Wheelchair areas	2

DPT: driving pantograph trailer MS: motor standard

Fig. 3—Train Formation.
The trainset which always consists of six cars has a total length of about 122 m. Both leading cars are fitted with automatic couplings with front hatches so that up to two trainsets can be coupled to allow operation with 12 cars per train.

line, the motor bogies and trailer bogies share the same design wherever possible for easer maintenance.

The driving cab houses the master controller along with various switches and monitors which surround the driver's seat, and also incorporates a crash pad that was optimized using the result of crash simulations analysis. An early mockup of the driving cab was fabricated so that it could be assessed by the drivers for ease of operation of switches and exterior visibility, and the results of this were reflected in the cab design.

DISTINCTIVE TECHNOLOGIES OF CLASS 395

In addition to the requirements of the UK customer, ensuring the rolling stock were compatible with the standards, operating practices, infrastructure, and other aspects of the local railway system were also important issues for the Class 395. This meant that several design features intended for Japan were not applicable. The following sections describe some representative examples of new technology development and testing carried out specifically for the Class 395.

Creating a Safe and Comfortable Vehicle Environment

Many of the standards relating to collision, strength, fire resistance, noise, and similar were very different to those that apply in Japan[2].

For example, cultural factors in Europe have led to stringent collision safety rules to ensure the safety of crew, passengers, and others in the event of a collision. To comply, the front-end of the Class 395 and the vehicle-end structure of each car adopted crashworthy structures that satisfy TSI (Technical Specifications for Interoperability) and the UK's RGS (Railway Group Standards). In the event of such an accident, the concept on which the design is based is that the crashworthy structures will crumple to absorb the crash energy and prevent the passenger and driver compartments from being crushed, thereby forming a survival space for the passengers and crew[3]. The driving cab, seats, tables, and other interior fittings have also been designed to comply with the crash safety requirements stipulated by the RGS, ATOC (Association of Train Operating Companies), and other standards.

For fire safety, regulations are also stipulated by a number of different standards including BS (British Standards), RGS, and ATOC. Apart from a small number of exceptions, all non-metallic materials used in the cars were required to satisfy BS fire retardancy rules and appropriate account was taken of this requirement when selecting the internal materials for the Class 395. The floor structure consists of carpet, floor boards and an underframe, and the overall structure of the vehicle-end including the insulation and inter-vehicle doors was designed to ensure fire resistance.

In addition to being subjected to detailed numerical analysis, unit testing, and other forms of evaluation[4], the performance of the structure of the Class 395 was

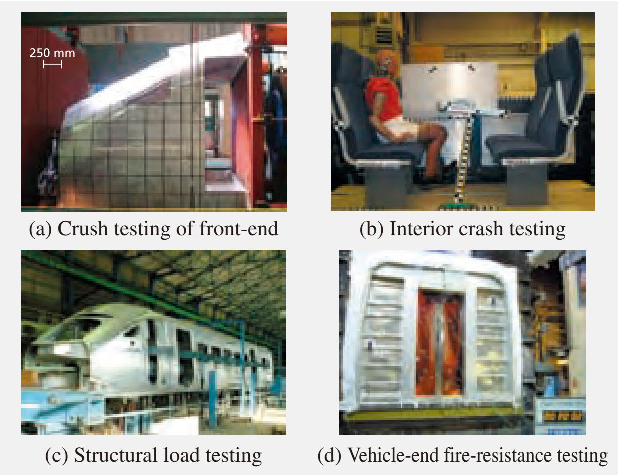


Fig. 4—Performance Verification by Testing.
Compliance with standards and the applicability of numerical analysis were verified by testing full-size specimens.

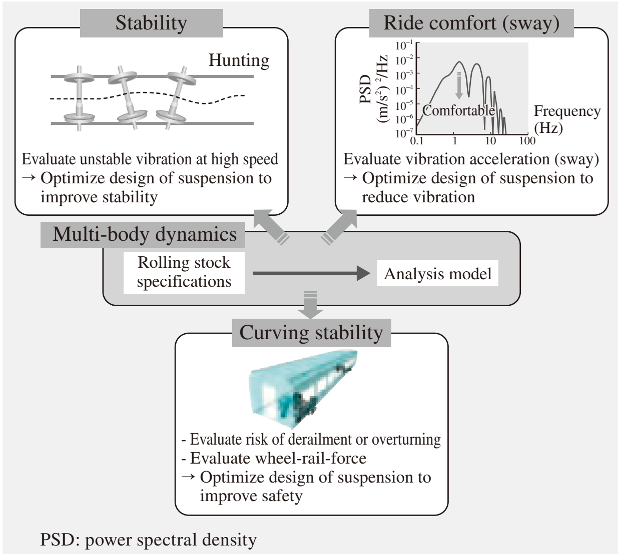


Fig. 5—Vehicle Dynamics Simulation.
This simulation technology can predict and evaluate safety and ride comfort by analyzing the movement and behavior of vehicle.

verified using various different tests including crash testing of full-size specimens, interior crash testing, static load testing, and fire-resistance testing, as indicated by the representative examples shown in Fig. 4. The trains were also subject to an audit by the UK Notified Body (NoBo) and were certified as complying with the standards.

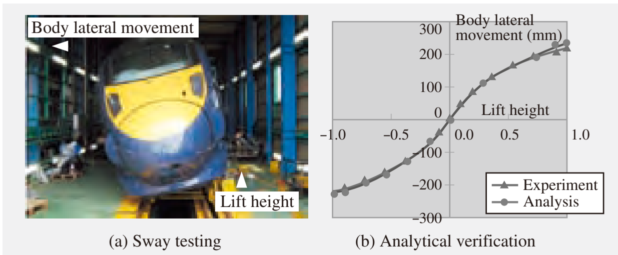


Fig. 6—Analysis for Sway for UK.
Non-linear situations with large displacements were carried out and produced results in good agreement with experiment.

Compatibility with UK Rail Infrastructure

(1) Gauging

As the existing UK railway lines did not have any static gauge that were applicable to the new vehicle, the manufacturer needed to determine the vehicle size based on the clearance from the line's stationary facilities and part of the certification process was to demonstrate that the train would not collide with these facilities. For this reason, a dynamic analysis of the lateral movement of the rolling stock was performed and the results were checked against the actual data for the stationary facilities so that the vehicle sizes and bogie suspension could be designed to ensure that sufficient clearance was available.

(2) Vehicle dynamics

The Class 395 is what is known in Japan as a high-speed existing line direct transfer train and needs to be able to negotiate the sharp curves smoothly on conventional line while also operating stably at a maximum speed of 225 km/h on the high-speed line. To satisfy this requirement, the vehicle dynamics simulation shown in Fig. 5 was used to optimize the bogie suspension to achieve stability, ride comfort, and curving performance. Also, to comply with UK standards, it was necessary to perform the special sway test shown in Fig. 6 (a) to provide a verification of the analysis of body lateral movement. As shown in Fig. 6 (b) the results of testing and analysis show good agreement for large displacements indicating that the analysis of body lateral movement provided sufficient prediction accuracy[(5)].

(3) Pressure variations in tunnels

In the UK and other European countries, the pressure variations inside and outside the vehicle when traveling through a tunnel must be kept within the standard of 10 kPa. This rule exists to minimize the effect on the tunnel walls by minimizing the pressure variations to which they are subjected, and also for considerations of passenger comfort. A computational fluid dynamics[(6)] was conducted to verify the level of these pressure variations in tunnels.

It is known that pressure variations in tunnels become greater when two trains are passing in opposite directions. Fig. 7 shows the results of an analysis conducted using a three-dimensional model of this case

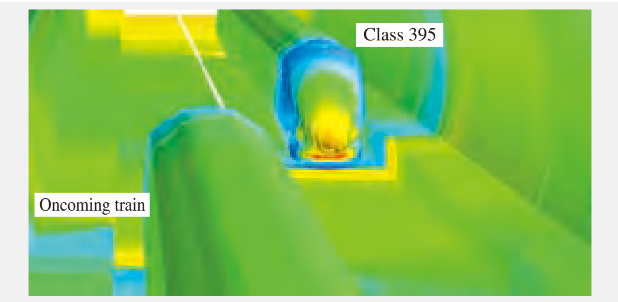


Fig. 7—Analysis of Trains Passing in a Tunnel.
An accurate analysis of the pressure variations that occur when two trains traveling in opposite directions pass in a tunnel can be carried out on a supercomputer.

when two trains traveling in opposite directions pass each other in a tunnel. The pressure variations in the tunnel were estimated from the results of this analysis to confirm that they would remain below the limit. In practice, the actual pressure variations will depend on the cross section, shape, and other characteristics of the tunnel, passing train, and other elements. To perform the assessment efficiently, therefore, all of the tunnels along the HS1 were tested using the single-dimension characteristic curve method and the computational fluid dynamics using a three-dimensional model only used on the worst cases to confirm that they remain within the limit.

Train Operation Control Suitable for Operating Practices Specification to UK

(1) TMS overview

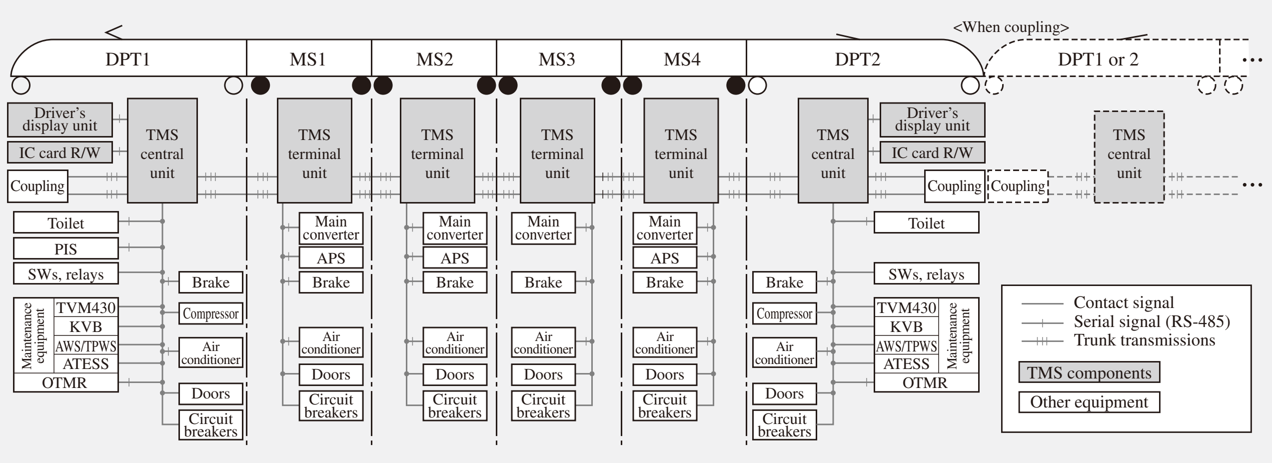
The TMS (train management system) is a system for providing the functions required by the crew and maintenance staff such as monitoring equipment status, equipment controlling, and self-diagnostics of equipment through the exchange of information via inter-vehicle trunk communications and communications with the on-board equipment.

The TMS for the Class 395 was developed based on the standard ATI-C[7] (autonomous decentralized train integration system with control command transmission) which uses fail-safe trunk communications with redundancy backup and obtained an SIL 2 (safety integrity level 2) safety rating under the IEC61508 standard due to the improved reliability of the SDO (selective door opening) function.

Fig. 8 shows a system block diagram of the TMS for the Class 395. The central unit located in the front-end vehicle and terminal units in each of the intermediate vehicle are connected together via a trunk transmission line with a communication speed of 3.2 Mbit/s and a redundant ladder topology. In addition to DIs (digital inputs) that receive the status of the master controller and other switches, power supply, and other components and DOs (digital outputs) that transmit signals such as the door release as one of the SDO function, serial communication is also used to handle communications with key equipment for monitoring and controlling. Also, touch-panel LCDs (liquid crystal displays) are used in the cab to display this status information, enter commands, and so on.

(2) SDO function

On conventional UK trains, it is common practice for the passengers to operate the open/close buttons



IC: integrated circuit R: reader W: writer TMS: train management system PIS: passenger information system SW: switch OTMR: on-train monitoring recorder
APS: auxiliary power supply TVM: transmission voice-machine KVB: contrôle de vitesse per balises AWS: automatic warning system
TPWS: train protection and warning system ATESS: Acquisition Temporelle Enregistrements Statiques

Fig. 8—TMS System Block Diagram.
The system block diagram of the TMS on the Class 395 is shown.

on each door after the crew use the "release operation" to unlock the doors. As dealing with stations where the platform is shorter than the length of the train is a regular occurrence, if all the doors are unlocked there is a risk of passengers inadvertently opening a door where there is no platform and falling from the train and therefore a function is needed to select which doors are safe to open based on the length of the platform at each station. As a requirement in the UK is to avoid as far as possible operations that require the crew to make decisions, an SDO function that can automatically select which doors are safe to open at each station is required.

As the SDO function determines which doors to unlock based on the current station, the function to detect which station the train has stopped at is critical. The SDO function fitted in existing trains uses GPS (global positioning system) to identify the station, but the problem with this approach is that it fails to work correctly if the GPS signal cannot be received such as in roofed stations. To deal with this problem, the station detection method in the SDO function on the Class 395, in addition to using GPS, also independently determines the station based on position information estimated from the train speed and then compares the results of the two methods. Door release control is then performed based on this station identification, railway line, and other information. The four standard cases for door release control are as follows.

(a) When traveling on HS1

As all of the stations along the HS1 high-speed line are guaranteed to have platforms longer than the maximum 12 cars that make up the train in the coupled configuration, station identification is not performed and all doors are unlocked when the train stops. The station checking screen appears on the driver's display unit when the door locks are released to display the current station and lock/release status of each door to the crew (see Fig. 9).

(b) Station identification results match

When traveling on a conventional line, if the stations detected by the GPS and distance traveled methods are the same, door release control operates on the assumption that the station identification is correct.

(c) Station identification results do not match

When traveling on a conventional line, if the stations detected by the GPS and distance-traveled methods are not the same, whether because the GPS signal cannot be received, the route has not been entered, or some other reason, the possible stations identified by the distance-traveled method are displayed on screen and the driver prompted to confirm the correct station. Door release control then proceeds based on the driver's selection.

(d) Station identification is unavailable

When traveling on a conventional line, if neither system is able to work because both the GPS signal cannot be received and the route has not been entered, or for some other reason, door release control is unable to function because the TMS has no information by which to identify the station. In this case, a screen containing a list of all stations is displayed and the driver selects the station to allow door release control to proceed.

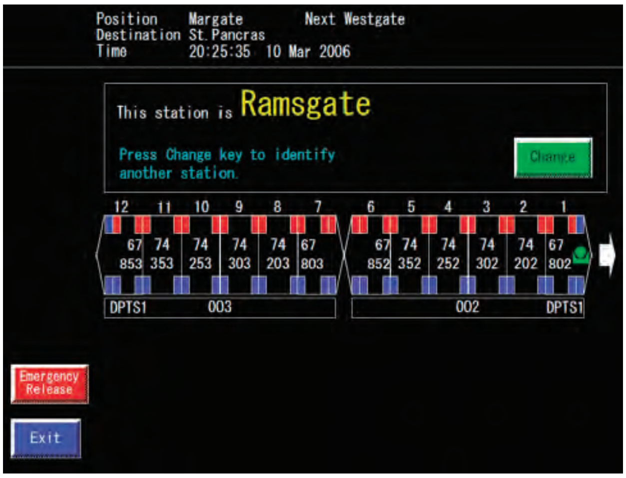


Fig. 9—Station Checking Screen.
The station checking screen is displayed on the driver's display unit.

MAINTENANCE

Consideration of Maintainability

As the terms of this project also included maintenance, maintenance considerations were included in the design from the earliest investigation stages.

As Hitachi did not have any past experience with rolling stock maintenance, an effort was made to visit railway operators in Japan to observe and learn maintenance techniques. The results of this initiative were collated in the design requirements to provide the designers with guidelines on maintainability. The design then proceeded in accordance with this design requirements document.

Construction of Maintenance Depot

The design and construction of the maintenance depot took place in parallel with the design and manufacture of the rolling stock, and the know-how needed to establish a maintenance depot was obtained with the cooperation of Japanese railway operators and reflected in the design of the actual depot. The following lists the factors taken into consideration in the depot construction.

(1) Layout specifically designed to suit the Class 395
(2) Optimization study of workflow
(3) Track layout designed for trouble-free shunting
(4) Encourage workforce minimization
(5) Establish data management practices based on information technology

Fig. 10 shows a diagram of the maintenance depot layout. Trains enter from point A where measurements are taken of the state of consumable items such as brake pads using automatic measurement equipment. This information is passed via a network to the depot management system where it is recorded and utilized in maintenance work. Next, the train is parked on stabling siding B and the track layout also allows it to move to shed C without needing a switchback. Shed C is designed in such a way that it can be used for all necessary inspection and repair work. Distribution store D is located next to shed C to optimize workflows by allowing the convenient movement of goods. The spacing between shed tracks is also designed to ensure adequate access for loading and unloading by forklift.

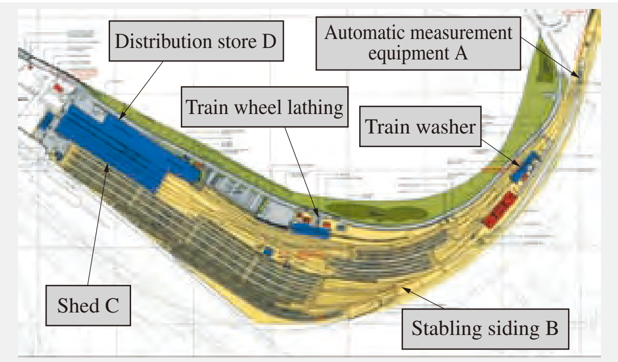


Fig. 10—Layout of Ashford Maintenance Depot.
The layout of the maintenance depot is specifically designed for maintaining the Class 395.

Maintenance Plan

Unlike Japan, there are no clearly determined standards for train maintenance established by law in the UK. Instead, the approach used is to formulate a maintenance plan for each train and to have this approved by the relevant auditing agency.

The Class 395 is a high-speed train with a maximum speed of 225 km/h and its maintenance plan was formulated based on the maintenance of Japanese Shinkansen trains. Table 2 lists the maintenance intervals for the Class 395 and summarizes what these involve.

TABLE 2. Class 395 Maintenance Intervals and Summary of Work
The types of inspections carried out and the details of what these involve are shown.

Inspection	Inspection work
Fitness to run	Inspect train prior to dispatch to check for any impediments to its operation.
7-day exam	Perform a visual inspection that looks in particular under the floor, on the roof, and in the cab. Perform operation checks on the brakes and doors.
28-day exam	Perform an inspection that looks in particular under the floor, on the roof, and at the doors. Also perform an internal inspection and operation checks. Clean the filters and replace any consumables as required.
56-day exam	Although this is essentially the same as the 28-day inspection, it is on a larger scale and includes inspection of long-interval parts. The pantograph operation check is also performed during this inspection.
168-day exam	In addition to the 56-day inspection items, operation checks are also performed on the signalling equipment.
336-day exam	Inspect all parts. Replace the hydraulic fluid.
Semi-overhaul	This inspection focuses on the bogies which are removed for disassembly and inspection at a dedicated facility.
Overhaul	In addition to the bogies, other major items of equipment are disassembled for inspection and repair. Inspection and repair of each item of equipment is performed at a dedicated facility.

Current Maintenance Situation

Commercial operation formally commenced in December 2009 with the trains being maintained in accordance with the plan and dispatched to the operating company on a daily basis. Overhauls are due to start during 2010 and, with the initial overhaul expected to be completed without incident, detailed planning is currently underway.

CONCLUSIONS

This article has given an overview of the Class 395 high-speed train for UK HS1 which is the first high-speed train from a Japanese rolling stock manufacturer to be supplied to Europe, and described its distinctive technologies and maintenance.

The Class 395 commenced commercial operation on-schedule in December 2009 and is helping increase the speed of domestic services in Southeast England. The train is also winning a good reputation for its ride quality and design.

Hitachi has added advanced technologies developed specifically for the Class 395 to its technologies for lighter weight and faster speed built up over past years, and its intention is to develop more comfortable and attractive trains suitable for European railway systems and to supply these together with maintenance services.

REFERENCES

(1) T. Yamada et al., “Latest A-train Railcar Enhancements,” Hitachi Review **53**, pp. 10–14 (Feb. 2004).

(2) T. Kawasaki et al., “Railway-vehicle Technologies for European Railways,” Hitachi Review **57**, pp. 61–65 (Mar. 2008).

(3) T. Mochida et al., “Development of Crashworthy Structure Composed of Aluminum Alloys for High-speed Railway Vehicle,” WCRR2008 (2008).

(4) K. Goda et al., “Simulation for Automotive and Railway Vehicles,” Hitachi Hyoron **90**, pp. 914–919 (Nov. 2008) in Japanese.

(5) M. Hidai et al., “Static Test of High Speed Vehicle for UK,” JRAIL 2007 (Dec. 2007) in Japanese.

(6) Y. Abe et al., “Analysis of Tunnel Micro-pressure Waves Using Compressible Fluid Analysis,” Proceedings of the Annual Meeting of The Japan Society of Mechanical Engineers 2009 (2), S0503-3-2, pp. 157–158 (2009) in Japanese.

(7) H. Koiwa et al., “B-system: New Solution for Seamlessly Interconnecting Track-side and On-board Systems over Network,” Hitachi Review **54**, pp. 169–173 (Dec. 2005).

ABOUT THE AUTHORS

Toshihiko Mochida

Joined Hitachi, Ltd. in 1999, and now works at the Rolling Stock Systems Design Department, Kasado Transportation Systems Product Division, Transportation Systems Division, Industrial & Social Infrastructure Systems Company. He is currently engaged in the development of rolling stock. Mr. Mochida is a member of The Japan Society of Mechanical Engineers (JSME).

Naoaki Yamamoto

Joined Hitachi, Ltd. in 2007, and now works at the Rolling Stock Electrical Systems Design Department, Mito Transportation Systems Product Division, Transportation Systems Division, Industrial & Social Infrastructure Systems Company. He is currently engaged in the development of train information system for railway rolling stock.

Kenjiro Goda

Joined Hitachi, Ltd. in 1995, and now works at the Vehicle System Department, Mechanical Engineering Research Laboratory. He is currently engaged in the research and development of bogies for railway rolling stock. Mr. Goda is a member of JSME.

Takashi Matsushita

Joined Hitachi, Ltd. in 1997, and now works at Hitachi Rail Europe Ltd. He is currently engaged in management of train maintenance.

Takashi Kamei

Joined Hitachi, Ltd. in 1993, and now works at the European Rail Business Development Division, Industrial & Social Infrastructure Systems Company. He is currently engaged in the development of European railway rolling stock business.