High Speed Trains
General Overview

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High Speed Trains
General overview
Contents

- Main characteristics
- Basic requirements, standards and certification
- Types of trains
- Technology
- Maintenance
- Economic aspects
Main characteristics  (1/2)

• Self-propelled, fixed-composition and bi-directional train, between 328 and 1,312 ft long (100 – 400 m long).
  (In Europe the standard length is 656 ft. Depending on the demand, two trainsets used, coupled together)
• Maximum speed of over 157 mph (250 km/h).
• Track gauge of 56.49 ins (1,435 mm).
• AC power supply, 15 or 25 kV.
• Maximum axle weight of 17.68 t (17 t + 4%) (1 t = 1,000 kg).
• High traction power, between 4 and 10 MW.
  (In the region of 8 MW for a train of 656 ft long – 200 m long)
• High rated traction power, in the region of 20 kW/t.
• In-cab signaling and communication systems.
• Improved commercial services.
Main characteristics (2/2)

- N700
- ICE3
- TGV Duplex
- ETR500
Contents

- Main characteristics
- Basic requirements, standards and certification
- Types of trains
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- Maintenance
- Economic aspects
Basic requirements

• Commercial.
• Technical and safety.
• Operation and maintenance.
• Compatibility with the infrastructure.
Commercial requirements  (1/3)

- Journey time.
- Number of commercial classes.
- Number of seats and layout.
- **Types of seats**: rotating seats, reclining seats, etc.
- Level of service for disabled passengers.
- On-board catering services.
- Buffet car equipment.
- Features of the air-conditioning equipment.
- Level of on-board entertainment: audio-video, Internet, etc.
- Level of customer service.
- **Other commercial aspects**: luggage registration, goods zone, public telephones, nursery, etc.
Commercial requirements  (2/3)

- **Journey time:** < 2h 30’ for 400 miles (650 km)
- **Commercial classes:** 2 or 3 (e.g. club-business-tourist)
- **Seats and layout:** 10% - club, 20% - business  
  70% - tourist
- **Types of seats:** rotating seats & reclining seats
- **Disabled passengers:** 2
- **Catering services:** lunch at seat (e.g. club & business)
- **Air-conditioning features:** 25 ºC + 41% RH car interior  
  (Spanish requirements)  with 40 ºC + 43% RH exterior
- **Entertainment:** audio-video
- **Other aspects:** goods zone, public telephone, nursery
Commercial requirements (3/3)

**Catering area**

1. Club car
   - 01-103 (end car Club)
   - 02-103 (transformer car Preferente)
   - 03-103 (converter car Preferente)
   - 04-103 (intermediate car Cafetería)

2. Buffet car
   - 05-103 (intermediate car Turista)
   - 06-103 (converter car Turista)
   - 07-103 (transformer car Turista)
   - 08-103 (end car Turista)

**Club car**

**Business cars**

**Tourist cars**

**Disabled passengers**

**AVE Class 103 layout**
Technical and safety requirements (European requirements)

• Compliance with UIC standards.
• Compliance with TSI (*Technical Specifications for Interoperability*).
• Compliance with railway EN standards.
• Compliance with national standards.
Technical and safety requirements (2/3)
Technical and safety requirements (3/3)

adif: Spanish Infrastructure Manager
(National standard)

N.T.C. MA 009

PRESCRIPCIONES TÉCNICAS DEL
MATERIAL RODANTE DE
ALTA VELOCIDAD
Operation and maintenance requirements

- Compliance with reliability standards.
- Compliance with availability standards.
- Compliance with standards of cleanliness and comfort.
- Good maintainability (*Achieving the appropriate level of ease of maintenance*).
Compatibility with the infrastructure  (1/2)

- Compliance with the gauge.
- Compatibility with the track: *respecting wheel/rail forces*.
- Respecting the minimum curve radius of workshops.
- Compatibility between the access doors and platforms.
- Voltage and frequency of the power station.
- Compatibility with the catenary: *height, zigzag and forces*.
- In-cab signaling systems: *ETCS, LZB, TVM, etc*.
- Respecting the level of harmonics and compliance with the electromagnetic compatibility standards.
Compatibility with the infrastructure (2/2)

- **DB: Hann-Würzburg**
  - 12.5 per thousand
  - Only passengers

- **AVE Mad - Sev**
  - 12.5 per thousand
  - Only passengers

- **LZB system**

- **TGV - PSE**
  - 35 per thousand
  - Only passengers

Mixed traffic:
freight + passengers

- **Catenary zig-zag: ± 11.81 ins (300 mm)**

- **AVE Mad - Bar**
  - 25 - 36 per thousand
  - Only passengers

- **LZB system**

- **Catenary zig-zag: ± 7.87 ins (200 mm)**
• In Spain there has been an evolution to the ETH (Technical Specification for Homologation – published in August 2009).

• ETH specifications have been prepared by expert groups, led by the Transport Ministry (Ministerio de Fomento).

• ETH is compliant with UIC, TSI, EN and national standards.

• ETH includes all the mandatory requirements to certify a rail vehicle: trainsets, locomotives, cars, wagons and special vehicles.
Technical Specification for Homologation (*ETH*)

(Mandatory after February 2010)
**Certification (3/6)**

Safety requirements based on the concepts: Tolerable Hazard Rate (THR)

Safety Analysis: Risk matrix to evaluate Frequency – Consequences of an accident.

<table>
<thead>
<tr>
<th>Frequency of accident</th>
<th>Insignificant</th>
<th>Marginal</th>
<th>Critical</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>Risk undesired</td>
<td>Risk intolerable</td>
<td>Risk intolerable</td>
<td>Risk intolerable</td>
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<tr>
<td>Probable</td>
<td>Risk tolerable</td>
<td>Risk undesired</td>
<td>Risk intolerable</td>
<td>Risk intolerable</td>
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<tr>
<td>Occasional</td>
<td>Risk tolerable</td>
<td>Risk undesired</td>
<td>Risk undesired</td>
<td>Risk intolerable</td>
</tr>
<tr>
<td>Remote</td>
<td>Risk negligible</td>
<td>Risk tolerable</td>
<td>Risk undesired</td>
<td>Risk undesired</td>
</tr>
<tr>
<td>Improbable</td>
<td>Risk negligible</td>
<td>Risk negligible</td>
<td>Risk tolerable</td>
<td>Risk tolerable</td>
</tr>
<tr>
<td>Highly improbable</td>
<td>Risk negligible</td>
<td>Risk negligible</td>
<td>Risk negligible</td>
<td>Risk negligible</td>
</tr>
</tbody>
</table>
Certification  (4/6)

• Safety Levels: Range of Tolerable Hazard Rate (TRH)

<table>
<thead>
<tr>
<th>Consequences of an accident</th>
<th>Frequency</th>
<th>THR (h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insignificant</td>
<td>Occasional-Probable</td>
<td>10⁻³ .. 10⁻⁵</td>
</tr>
<tr>
<td>Marginal</td>
<td>Remote</td>
<td>10⁻⁵ .. 10⁻⁷</td>
</tr>
<tr>
<td>Critical</td>
<td>Improbable</td>
<td>10⁻⁷ .. 10⁻⁹</td>
</tr>
<tr>
<td>Catastrophic</td>
<td>Improbable</td>
<td>10⁻⁷ .. 10⁻⁹</td>
</tr>
</tbody>
</table>
Certification: **Signaling**  (5/6)

- **Technical Specifications for Interoperability (TSI):**  Control-Command and Signaling.
- **EN standards:**
  - EN 50126: Specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS).
  - EN 50128: Communication, signaling and processing systems. Software for railway control and protection systems.
  - EN 50129: Communication, signaling and processing systems. Safety related electronic systems for signaling railway applications.

- The ERTMS system requires level 4 in the Safety Integrity Level (SIL).

  (in accordance with standard EN 50129).

<table>
<thead>
<tr>
<th>Index of Tolerable Dangers THR per hour and per function</th>
<th>Safety Integrity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-9} \leq \text{THR} &lt; 10^{-8}$</td>
<td>4</td>
</tr>
<tr>
<td>$10^{-8} \leq \text{THR} &lt; 10^{-7}$</td>
<td>3</td>
</tr>
<tr>
<td>$10^{-7} \leq \text{THR} &lt; 10^{-6}$</td>
<td>2</td>
</tr>
<tr>
<td>$10^{-6} \leq \text{THR} &lt; 10^{-5}$</td>
<td>1</td>
</tr>
</tbody>
</table>
Certification: **Signaling**  (6/6)

- According to the standards, the design and validation are carried out by means of what is called a “V” diagram.
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Types of trains

- **Concentrated power**, with one or two end power heads.
- **Distributed power**, with the technical equipment under the car bodies.
- **Conventional trains**, with two trucks per car.
- **Articulated trains**, with trucks shared between every two cars.
- **Tilting trains**, with active and natural systems.
- **Variable gauge trains**. *The trains can change the distance between wheels (gauge) in a specific facility.*
Concentrated/distributed power  (1/3)

• **Advantages of distributed power:**
  - Higher passenger capacity for a fixed length train.
  - Reduced axle load, more evenly distributed along the train.
  - Higher number of drive axles: *higher acceleration and better adhesion.*
  - Possibility of installing a higher traction power.

• **Drawbacks:**
  - Lower performance in cross wind conditions.
  - Higher possibility of electrical failures produced by the entrance of water, snow and ice, due to:
    - loss of airtightness in the electrical blocks.
    - entrance of moisture in non airtight electrical blocks under the carbodies.
Concentrated/distributed power  (2/3)

Distributed power

Concentrated power
Concentrated/distributed power (3/3)

ICE 2, Power head

Traction Converter
3 MVA

Traction Motor
1.2 MW

Main Transformer
5.22 MVA

ICE 3, 4 - car subunit

End car

Transformer car

Converter car

Trailer car

Traction motor
0.5 MW

Traction converter
2.3 MVA

Transformer
4.6 MVA

Traction converter
2.3 MVA
Articulated/non articulated trains (1/2)

- **Advantages of articulated trains:**
  
  ✓ **Good comfort for passengers:**
    - The intermediate trailer trucks are not under the passengers. Rides with less noise.
    - No lateral movement between cars. Passengers can move along the train more easily.
    - The height of the floor can be lowered, resulting in easier passenger access.

  ✓ Experience indicates good performance in case of derailment (*more rigid joint between cars*).
Articulated/non articulated trains (2/2)

Articulated train

Non articulated train
Tilting trains  (1/2)

• **Advantage of tilting trains:**
  
  ➢ Shorter travel times due to the ability to reach higher speed in curves.

• **Drawbacks:**
  
  ➢ More stress on the tracks in curves, due to a higher speed in curves.
  ➢ It is necessary to eliminate car motions of low frequencies (*under 1 Hz*) to avoid the risk that a small percentage of passengers have feelings of nausea.
Tilting trains

Active tilting

Natural tilting
Variable gauge trains  (1/2)

• **Advantages of variable gauge trains:**
  - Shorter journey times, because of wheel distance can be changed without stopping.
  - Better passenger comfort, because train changes are not necessary.

• **Drawbacks:**
  - Higher maintenance costs (*more complex bogies*).
  - Depending on the technology, it is necessary to eliminate the snow and ice on the axles before changing the wheel gauge.
  - Little experience of running with motor vehicles.
Variable gauge trains (2/2)

AVE - Class 130

AVE - Class 120

EMUs for 65.66 ins (1,668 mm) and 56.49 ins (1,435 mm) gauges (157 mph – 250 km/h)

(Both EMUs change the gauge in a specific facility at around 6 mph)
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• Main characteristics
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Technological challenges of High Speed

- The layout of the new High Speed lines.
- Wheel/rail contact. *Mechanical design.*
- Pantograph/catenary contact.
- Aerodynamic effects.
- Braking.
- Power.
- Control circuits. *Diagnosis system.*
- Speed control (*signaling*).
Layout of the new High Speed lines  (1/2)

- Very high curve radii, > 13,123 ft (4,000 m).
- High radius transition curves.
- Maximum gradients: the new lines, for passenger use only, allow for very high ramps (35-40 per thousand).
- Direct tracks through the stations (no platforms near direct tracks).
- No level crossings.
- Large section tunnels: in the region of 1,076.39 sq ft (100 m²).
Layout of the new High Speed lines (2/2)

HSL Madrid – Barcelona (Guadalajara-Zaragoza section)
Wheel/rail contact  (1/5)

- **A primary challenge**: High Speed would not be possible without good running stability.

- **Basically, the objective is to comply with the UIC-518 leaflet:**
  - **Safety**: Prud’homme limit, derailment coefficient, and instability criteria.
  - **Track fatigue**: Maximum vertical force, and lateral and vertical quasi-static forces in curves.
  - **Running quality**: Lateral and vertical accelerations.
Wheel/rail contact  (2/5)

- **Wheel/rail stress depends on:**
  - The train speed.
  - The characteristics of the track.
  - The characteristics and the state of the rolling stock.

- The increase in stress with speed is solved by a better quality of track and of truck design, and also, by appropriate maintenance.
Wheel/rail contact: Mechanical design (3/5)

- **Reduced axle load.** Light trains with evenly distributed axle loads (maximum 17.68 t/axle).
- **Reduced non-suspended mass** (the most aggressive). *Hollow axles help us to reduce the non-suspended mass.*
- **Reduced semi-suspended mass.** *Traction motors fixed under the carbodies.*
- **Trucks with a big wheel-base** (*big truck pitch, around 9.84 ft – 3 m)*.
- **Appropriate primary elasticities, wheel profiles and anti-yaw dampers**, are necessary to get a good running stability.
- **Concentration of masses in the centre of the truck.**
- **Pneumatic secondary suspension is desirable for comfort.**
Wheel/rail contact: Mechanical design (4/5)

TGV family & AVE Class 100
A wheel profile, with low conicity, is necessary to get a good running stability (the most common value is 2.5%).
Pantograph/catenary contact  (1/3)

- As the speed increases, the pantograph/catenary contact deteriorates.

- *This deterioration manifests itself by:*
  - sparks due to low pantograph contact force, and
  - excessive elevation of the contact wire (*excessive contact force*).

- *There are two criteria to measure the quality of the pantograph/catenary contact:*
  - Measuring the contact force, checking that it remains within optimal values.
  - Measuring the sparks produced during the current collection.
Pantograph/catenary contact

Renfe lab car
There are several ways of improving the pantograph/catenary contact:

- Constant height of the contact wire.
- Catenaries with uniform vertical elasticity, to avoid "hard points" in the masts and "soft points" in the center of two masts.
- Increase the mechanical stress of the contact wire.
- Pantograph with reduced mass, especially at the head, to minimize dynamic forces. 25 kV electrification enables the use of lighter heads.
- Reduce the number of raised pantographs, introducing a high-voltage line on the roof of the train.
- Regulate the vertical aerodynamic force, by means of active devices or ailerons.
- Catenaries with automatic temperature compensation.
Aerodynamic effects

- **Good aerodynamic design is essential to High Speed trains.** *(It can reduce resistance to forward motion, and thereby reduce the train power and the energy consumption).*

- **It is important to take into account that:**
  
  - The resistance to forward motion increases with the square of speed.
  
  - The necessary traction power increases with the cube of speed.
Aerodynamic effects  (2/4)

• **Good car design is needed to reduce the pressure variation for passengers in tunnels:**
  - Doors with inflatable joints.
  - Automatic closure of air-conditioning vents.
  - Airtight compartments.
  - Creation of excess pressure inside the train.

• **Large section tunnels** helps against the negative aerodynamic effects.
Aerodynamic effects  (3/4)

- **Two new aerodynamic problems arise when operating at very high speeds > 188 mph (300 km/h):**
  - The problem of speed limitation in relation to cross winds.
  - The ballast pick-up at high speed (*flying ballast*).

- These two phenomena are some of the problems that could limit operating speed.
Aerodynamic effects  (4/4)

A long nose helps against the negative aerodynamic effects.

AVE Class 102
Braking  (1/5)

• The large quantity of kinetic energy to be eliminated in High Speed trains requires a complete re-thinking of classic braking systems.

• The stopping distance is almost 2.5 miles (4 km) from 188 mph (300 km/h).

• Braking at High Speed is made by the joint automatic action of all the fitted brake systems: electric and pneumatic brakes.

• Electro-pneumatic controls must be used.
Braking (2/5)

- **Electric brakes:**
  - Preferably mixed: regenerative and rheostatic (*priority regenerative action*).
  - Must be independent of the existence of voltage in the catenary.
  - Automatic action with the pneumatic brake is required ("blending").
Braking (3/5)

- **Pneumatic brakes:**
  - Preferably with disks. *The trend is to eliminate the conventional shoe/wheel system to avoid wheel damages, due to the high temperature reached during the braking.*
  - For motor axles, semi-disks are used in both sides of the wheel.
  - **Some solutions:**
    - **TGV:** 4 disks/trailer axle
      4 shoe/wheel brake blocks/motor axle
    - **AVE Class 102:** Power heads: 1 disk/axle & 2 semi-disks/wheel
      Cars: 2 semi-disks/wheel & 1 disk/wheel
    - **ICE3:** Drive axles: 2 semi-disks/wheel
      Trailer axles: 3 disks/axle
Braking (4/5)

4 disks/trailer axle

1 disk/axle and 2 semi-disks/wheel

TGV family & AVE class 100

AVE Class 102
Braking (5/5)

• **Other braking systems used:**
  - Induction brakes (*Foucault or Eddy-current*).
  - Electromagnetic shoes.
  - Aerodynamic brakes (*solution in test*)

• **Advantages:**
  - Shorter stopping distances.

• **Drawbacks:**
  - Problems with the infrastructure: *Track erosion, harmonic interferences, etc.*
Power  (1/13)

- High power is needed: *triple/quadruple that of classic trains.* (Acceleration distance is around 12 miles up to 200 mph). (20 km up to 320 km/h).
- For reasons of commercial service reliability, it is also essential to have high power available as a precaution against breakdowns.
- Three-phase traction is possible for the development of power electronics:
  - *That made possible the use of lighter, more powerful and reduced-size traction motors.*
  - *Several independent power converters can easily be installed.*
- Three-phase synchronous or induction traction motors are used.
- Optimal electrification system 25 kV, 50 or 60 Hz.
Power: *Inverters*  (2/13)

Inverters to feed three-phase traction motors

Constant current inverter

Constant voltage inverter
Power: Inverters

Constant current inverter

Constant voltage inverter

Equal to:

- switch
- SCR-thyrister
- GTO-thyrister
- IGBT

SCR : Silicon Controlled Rectifier
GTO = Gate Turn-Off Thyristor
IGBT = Isolated Gate Bipolar Transistor
Power: Traction configurations (4/13)

(a) DC-Link
- Input filter
- Chopper: Variable voltage
- Inverter: Variable frequency
- Motor (M)

(b) DC-Link
- Input filter
- Chopper: Constant voltage
- Inverter: Variable voltage and frequency
- Motor (M) (VVVF)

(c) AC-Link
- Transformer
- Rectifier: Variable voltage
- Inverter: Variable frequency
- Motor (M)

(d) AC-Link
- Transformer
- Rectifier: Constant voltage
- Inverter: Variable voltage and frequency
- Motor (M) (VVVF)
Power: AVE class 100 diagram (5/13)
Power: AVE class 103 diagram  (6/13)

Velaro technology - Induction traction motors

Transformer

25 kV ~

CB ~

Input converters

Auxiliary converter

Auxiliary services

4QS1

4QS2

Lsk

Csk

DC - Link

PWM

Inverter

IM

IM

IM

IM
## Power: Semiconductors & cooling

### Power semiconductors:
- Diodes.
- Thyristors *(Silicon Controlled Rectifiers)*.
- Reverse conducting thyristors *(thyristor + anti-parallel diode)*.
- Gate Turn-Off thyristors *(GTOs)*.
- Isolated Gate Bipolar Transistors *(IGBTs)*.

### Cooling systems:
- Forced-air.
- Oil immersion.
- Liquid immersion *(vapor-cycle cooling system)*.
- Water.
Power: **Semiconductors & cooling**  (8/13)

Reduction ratio: 1 to 5 (in 10 years)

<table>
<thead>
<tr>
<th>Class</th>
<th>E-120</th>
<th>252</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyristors:</td>
<td>320</td>
<td>52 (GTOs)</td>
</tr>
<tr>
<td>Diodes:</td>
<td>160</td>
<td>52</td>
</tr>
<tr>
<td>Semiconductors:</td>
<td>480</td>
<td>104</td>
</tr>
<tr>
<td>Year:</td>
<td>1.980</td>
<td>1.992</td>
</tr>
<tr>
<td>Power:</td>
<td>5,6 MW</td>
<td>5,6 MW</td>
</tr>
</tbody>
</table>
Power: *GTO Phase Module*  

- **GTO-Thyristor:** 4,5 kV / 3 kA or 4 kA
- **Weight:** 70 kg
- **Max. DC link voltage:** 2,8 kV
- **Max. rms current:** 1,5 kA\(_{rms}\)
- **Switching frequency:** 350 Hz
- **Water temperature (inlet):** 55 °C
- **Module dimensions (W x H x D):** 17.71 ins x 16.33 ins x 12.28 ins
  - (450 mm x 415 mm x 312 mm)
Power: **ICE3 Multi-System** (10/13)

**Power container**

- Semiconductor devices:
  - GTO: 4.5 kV, 3.0 kA

- Container dimensions (W x D x H):
  - 133.85 ins x 86.61 ins x 17.71 ins (3,400 mm x 2,200 mm x 450 mm)

- Weight (without cooling equipment): 2,7 t

- Rated output power: 2,2 MW (AC line voltage only)

- Line voltages:
  - AC: 15 kV, 16.7 Hz; AC 25 kV, 50 Hz
  - DC: 1.5 kV; 3 kV
Power: **GTO-IGBT Technologies**  

- **GTO Technology**
  - Snubber circuit
  - **GU**: gate-unit
  - **GD**: gate-drive

- **IGBT Technology**
  - **Snubberless**
    - Reduced volume and weight
    - Increased efficiency
    - (no snubber losses)
    - Reduced Life Cycle Costs

- **AVC Class 102 technology**

Snubber circuit is not required.
### Power: Technology evolution

(12/13)

<table>
<thead>
<tr>
<th></th>
<th>Volume</th>
<th>Weight</th>
<th>Losses</th>
<th>Number of semiconductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTO Oil cooling</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>GTO Water cooling</td>
<td>88%</td>
<td>78%</td>
<td>100%</td>
<td>89%</td>
</tr>
<tr>
<td>IGBT Water cooling</td>
<td>48%</td>
<td>55%</td>
<td>50%</td>
<td>48%</td>
</tr>
</tbody>
</table>

- Modular design
- Increased efficiency

**Reduced Life Cycle Costs**
Power: *ICE3 Tractive&Braking curves*  (13/13)

**Ttractive effort – speed curve**

- **6000 kW**
- **40 \(\%_{\text{bo}}\)**
- **Forward motion resistance effort-speed curves**
- **5 \(\%_{\text{bo}}\)**
- **P\text{wheel} = 8000 kW**
  - (AC 15 kV 16.7 Hz)
  - (AC 25 kV 50 Hz)
- **75 \(\%\)** power-curve
  - (3 power converters)

**Braking effort – speed curve**

- **8200 kW**

**AC - Operation**
The control circuits (1/6)

• The control circuits are the vital part of a High Speed train. They consist of interconnected computers (*networks along the train*).

• All of the train equipment is connected to the computer networks.

• By means of the control circuits the driver and crew give orders to the train devices.

• The control circuits are redundant.

• Normally a control circuit takes the train control (*master*) and the others are in stand-by (*slaves*).

• In case of failure of the master controller, a slave device takes control automatically and starts working as a master.
The control circuits: Control diagram (2/6)

Locomotive Class 252
The control circuits: *Computer network* (3/6)
The control circuits: *Equipment connected to the train computer networks* (4/6)

- Power equipment.
- Braking and anti-skid equipment.
- Auxiliary service equipment.
- Signaling and communication systems.
- Juridical recorders.
- Truck instability detectors.
- Temperature detectors in axle boxes.
- Fire detectors.
- Passenger information systems.
- Other equipment: *air-conditioning, door controls, lighting, etc.*
- Diagnosis systems, to transmit incidents to the maintenance center.
The control circuits: *Diagnosis system* (5/6)

- High Speed trains have a diagnosis system to identify breakdowns on board.

- *The diagnostic system automatically sends to the workshop a series of data via GSM digital telephone:*
  - Information generated by the train.
  - Information entered by the driver and/or the train crew.

Maintenance operations are planned on the basis of the above information.
The control circuits: Diagnosis system DMI information (6/6)
Speed control (signaling)  (1/3)

- The classic system of vertical signals is not valid at High Speed.

- **Signaling at High Speed has to fulfil the following requirements:**
  
  - In-cab signaling: real speed, permitted speed, target speed, distance to go.
  - Continuous transmission of information is desirable.
  - Automatic breaking action, if the permitted speed is exceeded.
Speed control (signaling)  (2/3)

- *Existing systems:*
  - ATC (*Shinkansen*).
  - TVM (*TGV*).
  - LZB (*ICE and AVE Madrid-Seville*), etc.
  - In Europe, the signaling systems diversity has presented a considerable difficulty to the interoperability.
  - This will be overcome with the new European ERTMS system.
Speed control (signaling)  (3/3)
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Goals of rolling stock maintenance

• *To provide rolling stock which is fully operational for commercial service:*
  - In complete safety.
  - At the required level of reliability.
  - At the right time (*availability*).
  - At the best cost (*or price*).

• The maintenance policy defines the best balance between corrective and preventive maintenance, which are complementary activities.
Specific requirements from the trainset design

The basic principles of maintenance must be taken into account when the rolling stock is designed:

- Accessibility, modularity and interchangability.
- Maintainability.
- Ease and quick repair, in case of failure.
Rolling stock maintenance management

- As a rule, it is necessary to design, implement and evolve guidelines for rolling stock maintenance, with a view to optimizing costs, while guaranteeing rail traffic safety.

- Maintenance organisation is based on hierarchical maintenance activities, into several increasing levels, depending on work complexity (standard EN 13306).
The different kinds of maintenance  

**PREVENTIVE MAINTENANCE**

- **CONDITIONAL PREVENTIVE**
  Replacement of components in accordance with measurable CRITERIA

- **SYSTEMATIC PREVENTIVE**
  Replacement of components according to their POTENTIAL working life *(time or distance)*

**CORRECTIVE MAINTENANCE**

After a failure
The different kinds of maintenance (2/6)

PREVENTIVE MAINTENANCE

“Low level”, quick and simple operations and cleaning

“High level”, more complex operations, obliging removal of the vehicle from commercial service for several days
The different kinds of maintenance (3/6)

**LEVEL 1: CHECKS IN SERVICE**
- Low level maintenance.
- Checking security elements, especially under the carbody: axles, brakes, etc.

**LEVEL 2: CHECKS & OPERATIONS ON DEDICATED WORKPLACES**
- Low level maintenance.
- Quick interventions between two services
- Application of preventive and corrective maintenance plan. External cleaning.
LEVEL 3: PERIODIC VISITS TO MAINTENANCE CENTER

- High level maintenance.
- Interventions requiring removal from service.

LEVEL 4: MAJOR PERIODIC OPERATIONS AT INDUSTRIAL MAINTENANCE FACILITY

- High level maintenance.
- Major components repair.
The different kinds of maintenance (5/6)

LEVEL 5: MODERNISATION OR MODIFICATION AT INDUSTRIAL MAINTENANCE FACILITY

- High level maintenance.
- Trainset overhaul (*interior design & component upgrades*).
- Interventions requiring removal from service, during several weeks.
The different kinds of maintenance (6/6)

• Depending on the number of trainsets to maintain, the network size and the different levels, it is possible to preview different types of maintenance workshops.

• It’s necessary to implement a methodology for the elaboration and update the rules and maintenance cycles, taking into account:
  - The security requirements.
  - The availability and quality objectives.
  - The accumulated experience.
  - Technical tests, etc.
The cycles of maintenance. **TGV trainsets case**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time/Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning (or GVG)</td>
<td>3,125 miles 8 days</td>
</tr>
<tr>
<td></td>
<td>22 days</td>
</tr>
<tr>
<td></td>
<td>37 days</td>
</tr>
<tr>
<td></td>
<td>52 days</td>
</tr>
<tr>
<td></td>
<td>168 days</td>
</tr>
<tr>
<td></td>
<td>281,250 miles or 10 months</td>
</tr>
<tr>
<td></td>
<td>562,500 miles or 18 months</td>
</tr>
<tr>
<td></td>
<td>1,125,000 miles or 36 months</td>
</tr>
</tbody>
</table>

**ES**: checks in service  
**ECC**: comfort checks  
**EMN**: mechanical checks  
**VL**: limited level checks  

**VG**: general level checks  
**ATS**: another systematic works  
**GVG**: complete level checks

**Half-life Overhaul**: 15 years (modular Operations)
Rolling stock purchasing process

• Issuing of a “call for tenders” leads to a purchase contract, signed between the Operator and a rolling stock Supplier.

• This purchase contract contains three kinds of clauses:
  - Technical and operational clauses (mission pattern, RAMS and LCC).
  - Project management clauses (e.g. manufacturing plan).
  - Commercial clauses (e.g. price, financial penalties).

• The schedule up to signing a contract can reach 5 years.

• The cost of the above mentioned process can be between 700,000 $ and 1,400,000 $
Implementation of specific procedures

- Security action plan.
- Facilities organisation (workshops).
- Staff training.
- Personnel qualification and development.
- Work control procedures and statistical monitoring.
- Experience feedback.
- Quality assurance (ISO 9000 certification).
LCC – The Iceberg of the costs structure

Purchasing
(design, production, testing)

Commercial operation
(staff, facilities …)

Handling, empty trips to
workshop …

Software maintenance &
upgrades

General Maintenance &
Half-life overhaul

Testing and Support
equipments

Documentation

Supplies

Training

Decommissioning
and scrapping
Maintenance approach evolution

**TRADITIONAL**
- Full responsibility and works carried out in-house

**CUSTOMER/SUPPLIER**
- Full responsibility, subcontracting some activities
  - **PARTICIPATION**
    - Products deliver, Warranty obligations and carry out requested activities

**WIN-WIN**
- • Risk and responsibility transfer
  - • Mutual objectives commitments

- • Risk Manager
  - • Full responsibility over maintenance
  - • Mutual objectives commitments
AVE maintenance case  (1/6)

• **When AVE was created, in 1990, Renfe made two decisions:**
  - AVE should be an Organization sized right in resources and focused on its “core business”: passenger transport by high speed rail.
  - All the non-core activities should be subcontracted (*turnkey contracts*).

• **Renfe had positive experiences of contracting the rolling stock maintenance:**
  - Talgo cars from 1950.
  - Class 446 trainsets from 1990.

• In 1992, when AVE started commercial services, Renfe decided to continue with the same model.
• With this model, workshops, facilities and capital spare parts are provided by AVE.
AVE maintenance case: *Contract requirements*  (2/6)

- **Preventive and corrective maintenance**, with commitment to introduce “on-condition” maintenance procedures.
- **Exterior and interior cleaning**.
- **Availability, reliability, comfort & cleaning commitments:**
  - *Contract availability:* 100% of the agreed commercial plan.
  - *Contract reliability:* based on 10-minute delay on departure or arrival (Average distance between delays: 625,000 miles).
- **Flexibility to adapt maintenance plans and overhaul activities to commercial needs** (*optimal adjustments of daily operation diagrams*).
- **Technical and maintenance support in case of vehicle incidents on track**.
- **24hr/365 days on-call emergency rescue team**.
- **Vandalism and minor accidents repair**.
AVE maintenance case: *Contract requirements* (3/6)

- Technical support, product improvements and technical documentation update.
- Facilities maintenance.
- Control of the rolling stock movement within the maintenance workshop.
- Quality commitment: *ticket refund if more than 5 minutes delay*.
- *Renfe* participates, together with the manufacturers, in the maintenance of the trains up to 50%, via mixed companies.
AVE maintenance case: *Contract Controls*  (4/6)

- **Technical audits made by:**
  - AVE Rolling Stock Directorate
  - Renfe Safety Directorate
  - Infrastructure maintenance and Safety Directorate of Adif (*Spanish Infrastructure Manager*)

- **In Operation Controls made by AVE:**
  - Operations Directorate (*daily reports fulfilled by the drivers and ticket inspectors*)
  - Commercial Directorate (*audits and daily reports fulfilled by the on-board services personnel*)
  - Quality Department (*audits*)
  - Rolling Stock Directorate (*audits and inspections*)
**AVE maintenance case: Contract Controls** (5/6)

- **Manufacturer Reports:**
  - Level of accomplishment of the maintenance plan
  - Delays and incidents in commercial service
  - Monthly summary of the operation, maintenance and cleaning (*trains behaviour*)

- **Online computer access to the maintenance management systems of the manufacturers**

- **Customer quality perception surveys**

- **In line incidents analysis, with the Traffic Control Office of Adif** (*weekly meetings*)

- **Penalties for not reaching the commitments**
AVE maintenance case: Operator’s benefits (6/6)

• It allows the Operator to focus on its own core business.

• Predictability of long-term maintenance costs of the rolling stock and workshop facilities.

• Optimization of the operations management and of the fleet maintenance management:
  - Performance commitments agreed with manufacturer.
  - Flexibility to quickly respond to new requirements, allowing continuous improvements of commercial services.
  - Reliability improvement due to the interest of the manufacturer in introducing solutions to avoid defects in service and to reduce its own costs.
  - Availability improvement based on a bigger guarantee of supply of strategic spare parts.
Contents

• Main characteristics
• Basic requirements, standards and homologation
• Types of trains
• Technology
• Maintenance
• Economic aspects
## Economic aspects - *Some significant data for a train of 656 ft long (average)*:

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mileage per trainset</td>
<td>312,500 miles</td>
</tr>
<tr>
<td>Maintenance man hours per trainset</td>
<td>20 every 625 miles (first level)</td>
</tr>
<tr>
<td>Workforce per trainset</td>
<td>5 or 6 technicians (first level)</td>
</tr>
<tr>
<td>Price per seat</td>
<td>about 85,000 $</td>
</tr>
<tr>
<td></td>
<td>(57,000 – 100,000 $ depending on the rolling stock classes)</td>
</tr>
<tr>
<td>Wheel potential working life</td>
<td>812,500 miles</td>
</tr>
<tr>
<td>Gear boxes potential working life</td>
<td>1,406,250 miles</td>
</tr>
<tr>
<td>Traction motor potential working life</td>
<td>1,500,000 miles</td>
</tr>
<tr>
<td>Current maintenance cost</td>
<td>between 3 and 5 $/mile</td>
</tr>
<tr>
<td></td>
<td>(depending on the trainset generation)</td>
</tr>
<tr>
<td>Life cycle of a trainset</td>
<td>between 20 and 40 years</td>
</tr>
<tr>
<td></td>
<td>(it is important to take into account the decommissioning and scrapping tasks)</td>
</tr>
</tbody>
</table>
Thank you for your attention