High Speed Rolling Stock in Japan

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Contents

- Introduction of UIC Report “Necessity of future high speed rolling stock”

- Introduction of Shinkansen rolling stock
  - Basic idea and variety

- Features of Shinkansen rolling stock for
  - Safe, Reliable, Comfortable, Convenient Transportation

- Maintenance

- Closing remarks
Aim:
Show general overview of issues which should be taken into account for future high speed rolling stock under the changing business and technical situations from a global perspective

Report structure
1 General Issue (mainly in Business aspects)
   Development, Procurement, Approval, Deployment, Maintenance, Life Cycle Cost, RAMS (Reliability, Availability, Maintenability, Safety), Standardization, Compatibility with infrastructure
2 Basic technical aspects
   Dimensions, Performance, Safety, Environment, Aerodynamics, Comfort
3 Commercial and human factors
   Ergonomics, PRM, Drivers cab, Cabin, Services
4 Other technical aspects
   Body structure, Power/Brake system, Train control, Others

UIC member will soon be able to refer to this report
World High Speed Rolling Stock table can be referred to by all people
http://www.uic.org/
Basic idea of Shinkansen rolling stock design

- High Speed dedicated infrastructure aimed at high speed, high capacity, and high level of safety like
  - Large curve radius
  - Less gradient
  - No level crossing
  - In-cab signaling (ATC)
  - Large loading gauge etc.

**Rolling stock was designed as part of total HSR system**

- Distributed power (Electric Multiple Unit) for
  - Light axle load
    - Low construction/maintenance cost of infrastructure
    - Low ground vibration emission etc
  - High adhesion performance
    - Capable of high acceleration/deceleration
  - "Multiple unit"=Robust against failure

**Rolling stock aimed at better operational performance**

- Currently the variety has increased to meet customer/operational needs
  **Interoperable rolling stock** to conventional line (smaller loading gauge),…
<table>
<thead>
<tr>
<th>Line</th>
<th>Section</th>
<th>Length (mile)</th>
<th>Max. Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokaido</td>
<td></td>
<td>343.4</td>
<td>168</td>
</tr>
<tr>
<td>Sanyo</td>
<td></td>
<td>400.2</td>
<td>187</td>
</tr>
<tr>
<td>Tohoku</td>
<td></td>
<td>392.6</td>
<td>171</td>
</tr>
<tr>
<td>Joetsu</td>
<td></td>
<td>188.6</td>
<td>150</td>
</tr>
<tr>
<td>Nagano</td>
<td></td>
<td>72.9</td>
<td>162</td>
</tr>
<tr>
<td>Kyushu</td>
<td></td>
<td>85.5</td>
<td>162</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td></td>
<td><strong>1483.3</strong></td>
<td></td>
</tr>
<tr>
<td>Akita</td>
<td></td>
<td>79.1</td>
<td>81</td>
</tr>
<tr>
<td>Yamagata</td>
<td></td>
<td>92.3</td>
<td>81</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td></td>
<td><strong>171.4</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1654.7</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Length: mileage in revenue service

Converted from narrow gauge to standard gauge
Structure of Shinkansen traffic

Network is expanding, environment is changing

Northbound from Tokyo:
  Traffic is as a tree structure of which the root is thick
  • Destinations are smaller cities
  • Smaller population density along the line
  • Large density in Tokyo metropolitan area
  • Branch lines including converted conventional gauge line

  Tend to have wide variety of rolling stock depending on the demand

West bound from Tokyo:
  Traffic is almost stable on the entire line
  • Destinations are large cities
  • Chain of large cities along the line

  Tend to have rolling stock with unique specification
## Variety of Shinkansen rolling stock operated in Japan

<table>
<thead>
<tr>
<th>Series</th>
<th>Number of cars in a set</th>
<th>Year in service</th>
<th>Max speed (km/h)</th>
<th>Passenger capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6 or 4</td>
<td>1985-</td>
<td>220</td>
<td>394 (6)</td>
</tr>
<tr>
<td>300</td>
<td>16</td>
<td>1992-</td>
<td>270</td>
<td>1323</td>
</tr>
<tr>
<td>500</td>
<td>16 or 8</td>
<td>1996-</td>
<td>300</td>
<td>1324 (16)</td>
</tr>
<tr>
<td>700</td>
<td>16</td>
<td>1998-</td>
<td>285</td>
<td>1323</td>
</tr>
<tr>
<td>700-7000</td>
<td>8</td>
<td>2000-</td>
<td>285</td>
<td>571</td>
</tr>
<tr>
<td>N700</td>
<td>16</td>
<td>2007-</td>
<td>300</td>
<td>1323</td>
</tr>
<tr>
<td>800</td>
<td>6</td>
<td>2004-</td>
<td>260</td>
<td>392</td>
</tr>
<tr>
<td>200</td>
<td>10</td>
<td>1982-</td>
<td>240</td>
<td>762</td>
</tr>
<tr>
<td>400</td>
<td>16</td>
<td>1992-</td>
<td>240</td>
<td>399</td>
</tr>
<tr>
<td>E1</td>
<td>12</td>
<td>1994-</td>
<td>240</td>
<td>1235</td>
</tr>
<tr>
<td>E2</td>
<td>8</td>
<td>1997-</td>
<td>275</td>
<td>630</td>
</tr>
<tr>
<td>E2-1000</td>
<td>10</td>
<td>2002-</td>
<td>275</td>
<td>814</td>
</tr>
<tr>
<td>E3</td>
<td>6</td>
<td>1997-</td>
<td>275</td>
<td>338</td>
</tr>
<tr>
<td>E3-1000</td>
<td>7</td>
<td>1999-</td>
<td>275</td>
<td>402</td>
</tr>
<tr>
<td>E3-2000</td>
<td>7</td>
<td>2008-</td>
<td>275</td>
<td>394</td>
</tr>
<tr>
<td>E4</td>
<td>8</td>
<td>1997-</td>
<td>240</td>
<td>817</td>
</tr>
</tbody>
</table>

Source: UIC "World high speed rolling stock"
Example of the variety of Shinkansen series

Three typical types of Shinkansen rolling stock for NORTHBOUND

- Fast and high capacity transportation on main lines
- Fast and capable of through operation to converted conventional lines
- Highest capacity for commuter transport

**Series E2 (E2-1000)**
“Standard” type

**Series E3**
Mini-Shinkansen type

**Series E4**
Double decker type

Based on similar technical concept to the west bound rolling stock
# Comparison of typical rolling stock for northbound

<table>
<thead>
<tr>
<th></th>
<th>E2-1000</th>
<th>E3</th>
<th>E4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Series</strong></td>
<td>E2</td>
<td>E3</td>
<td>E4</td>
</tr>
<tr>
<td><strong>Train Configuration (train length)</strong></td>
<td>8M2T (251m)</td>
<td>4M2T (128m)</td>
<td>4M4T (201m)</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>814</td>
<td>338</td>
<td>817</td>
</tr>
<tr>
<td><strong>Capacity /m</strong></td>
<td>3.24</td>
<td>2.56</td>
<td>4.06</td>
</tr>
<tr>
<td><strong>Approx. Max. axle load (loaded)</strong></td>
<td>13.2t</td>
<td>12.2t</td>
<td>16t</td>
</tr>
<tr>
<td><strong>Max. operating speed</strong></td>
<td>171mph</td>
<td>171mph (81mph on conventional)</td>
<td>149mph</td>
</tr>
<tr>
<td><strong>Intermediate Car length</strong></td>
<td>25m</td>
<td>20.5m</td>
<td>25m</td>
</tr>
<tr>
<td><strong>Body width</strong></td>
<td>3380mm</td>
<td>2945mm</td>
<td>3380mm</td>
</tr>
<tr>
<td><strong>Motor power (continuous)</strong></td>
<td>300kW</td>
<td>300kW</td>
<td>420kW</td>
</tr>
<tr>
<td><strong>Coupling with (in normal operation)</strong></td>
<td>E3</td>
<td>E2</td>
<td>E4 (E3-1000, 2000, 400)</td>
</tr>
<tr>
<td><strong>Electrical system</strong></td>
<td>AC25kV50Hz</td>
<td>AC25kV50Hz</td>
<td>AC25kV50Hz</td>
</tr>
<tr>
<td><strong>Signalling system</strong></td>
<td>DS-ATC</td>
<td>DS-ATC, ATS-P</td>
<td>DS-ATC</td>
</tr>
<tr>
<td><strong>Year in operation</strong></td>
<td>2002</td>
<td>1997</td>
<td>1997</td>
</tr>
</tbody>
</table>
Features of Shinkansen rolling stock

- Large loading gauge
  - High capacity
    - 5 seats/row, easier application of double decker
  - High comfort by larger space

- Light maximum axle load
  - Around 11-13 ton for single deck Shinkansen
  - Distributed power
    - Heavy components are distributed
  - Reduction of total weight
    - Light weight car body
      - Body shell, bogie, components,…
    - Structural strength against collisions can be reduced because of dedicated track
  - Light weight will also reduce the energy consumption!

*Mini-shinkansen has a smaller (same as conventional) loading gauge*
Features of Shinkansen rolling stock

- Distributed power (Electric Multiple Unit)
  - Light axle load
  - High rail/wheel adhesion performance
    - High acceleration/deceleration
    - Effective especially in case of slippery situation
  - Large passenger capacity without locomotive
  - "Multiple unit" = Robust against the failure

Ex. Series E2-1000

In case of failure of one unit
Main circuit failure: train runs by the rest of units
Auxiliary unit failure: service power is provided from other units
Features of Shinkansen rolling stock

- **Basic body design**
  - Double skin aluminum alloy body in latest cars
    - Easy construction (possible to lower cost)
    - Stiff but light weight
  - Air tight body with continuous ventilation system
    - Avoiding internal pressure fluctuation in cabin
  - No standard strength value for collision
    - Mini-Shinkansen type is designed under consideration of level crossing collision
  - …

- **Cabin design**
  - Every seat assures an outside view through the window
  - Rotating seat
  - Flatness of platform and cabin floor
    - Easy access for PRM (must be compatible with infrastructure)
  - …
  - No bistro car but catering space

*Cabin design strongly depends on customer needs!*
Features of Shinkansen rolling stock

- **Body design for environment**
  - Tunnel micro pressure wave reduction
  - Optimized nose shape

- **Line side noise reduction**
  - Measures for aerodynamic noise
    - Pantograph (smooth design, reduction of the number in a set, …)
    - Smooth surface of the train (cover at car gaps and so on, …)
  - Positive effect on reduction of aerodynamic resistance
  - Reduction of energy consumption
  - Reduction of noise from electrical and mechanical components

*Design must be combined with infrastructure measures.*
*Measures depend on the local standard.*
*Japan strongly needs noise reduction because Shinkansen runs in residential area.*
Features of Shinkansen rolling stock

- **Bogie design**
  - Safety running is assured with
    - Light weight structure (bolster-less type)
    - High level of ride comfort
  - Difference between Shinkansen and Mini-Shinkansen
    - Wheel base, Wheel profile, … compatible with infrastructure

- **Active suspension**
  - Reduce lateral vibration of car body by actuators to increase riding comfort

- **Tilting system by air suspension control**
  - Adopted on newest cars to allow increased speed on curves while maintaining riding comfort
Features of Shinkansen rolling stock

- Main circuit system
  - VVVF control, Induction motor
  - Low maintenance, energy efficiency mainly by regenerative brake
  - Compact package is necessary especially for distributed powered train

- Train on-board information control system
  - Important function can be controlled by back-up system
  - Compatible with traffic control system

Display for the driver

Transmitted by Digital Wireless Radio

Supporting for emergency in trouble

Dispatchers' Room
Features of Shinkansen rolling stock

- **Braking system**
  - Mixture of *regenerative brake* and mechanical brake
    - Maximize energy efficiency
    - Reduction of wear of braking pad
    - Back-up by the mechanical brake in case of failure or shortage of regenerative brake

- **Three brakes**
  - Service brake
    - Activated automatically by ATC or manually by the driver
  - Emergency brake
    - Activated automatically by ATC or manually by the driver in case of emergency situation
    - Braking force is increased from maximum value of service brake
  - Urgent brake
    - Automatically activated in case of accidental decoupling. etc.
## Reduction of train operation energy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Train set configuration</strong></td>
<td>16-car configuration (16M)</td>
<td>10-car configuration (8M2T)</td>
</tr>
<tr>
<td><strong>Train weight</strong></td>
<td>970t/16cars (loaded)</td>
<td>442t/10cars (unloaded)</td>
</tr>
<tr>
<td></td>
<td>[Avg. 60.6t/car (loaded)]</td>
<td>[Avg. 49.6t/car (loaded)]</td>
</tr>
<tr>
<td><strong>Max. axle load</strong></td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td><strong>Power control system</strong></td>
<td>Continuous thyristor phase control</td>
<td>VVVF inverter control</td>
</tr>
<tr>
<td><strong>Braking system</strong></td>
<td>Rheostatic braking</td>
<td>Regenerative braking</td>
</tr>
</tbody>
</table>

Energy consumption (10-car equivalence estimate) $-40\%$ 

-18%
Features of Shinkansen rolling stock

- Safety system is designed to:
  - Reduce human errors
  - Assure safety by automated system
  - Apply fail-safe concept
- ATC in-cab signalling system
  - Digital ATC
    Digital ATC has been modified from conventional ATC system
    - to increase the capacity of lines
    - to improve riding comfort
- Redundancy by multiplexing on-board system for safety and reliability
Features of Shinkansen rolling stock

- Coupling system (used in northbound Shinkansen)

- Fast and reliable system was developed to fit operation needs.

- Separating time: 2.5min
- Coupling time: 1.5min

<Tokyo ~ Morioka>
- Coupled operation of Series E2 & E3

<Morioka ~ Akita>
- Series E3 operation
- Operating speed: 130 km/h
  (converted conventional line)

Tokyo ~ Morioka ~ Akita ~ Hachinohe
Features of Shinkansen rolling stock

- Measures for natural conditions
  - Earthquake
    - Niigata Chuetsu Earthquake (2005)
    - Measures have been applied to avoid catastrophe after derailment (JR East case)
    - Earthquake measures are combined with infrastructure (earthquake detection system, anti-derailment measure on infrastructures)
  - Snow (mainly for northern bound Shinkansen)
    - Researching to avoid adhesion to the body
      Detached snow may hit the ballast
    - Snowproofing components
    - Snow plow

Measures should be combined with infrastructure measures
Elements to be taken into account strongly depend on the natural condition of the country humidity, high or low temperature, …
Maintenance

Preventive maintenance

<table>
<thead>
<tr>
<th>Maintenance Level</th>
<th>Inspection Intervals</th>
<th>Daily Inspection</th>
<th>Regular Inspection</th>
<th>Bogie Inspection</th>
<th>Overall Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 days 30,000km (18,641mi)</td>
<td>2 days</td>
<td>1.5 year 600,000km (372,822mi)</td>
<td></td>
<td>3 years 1,200,000km (745,645mi)</td>
</tr>
</tbody>
</table>

- Daily inspection
  - Inspection of wear parts (pantograph strip, …), Refreshing water/waste …
- Regular inspection
  - Condition and function test, Inspection of important parts/components without decomposition (axle, …)
- Bogie inspection
  - Inspection of bogie parts by decomposition
- Overall inspection
  - Inspection of overall rolling stock by decomposition

Maintenance is managed by operators

Distribution of maintenance base

- Example of JR East case
  - (Total: 9 series, 131 sets)
Maintenance

- Reliability

Fluctuation in rolling stock failures (Data of JR East)
(Number of failures per 1 million kilometer (621,371 mile) over 1987~2000)

- High reliability assures high efficiency of train set use
  *The number of train sets can be kept to as few as possible!

Ex. Series E4 (JR East) case
Total number of train sets: 26 sets
  - In operation: 25 sets
    (including maintenance work)
  - Stand-by: 1 set

96.2% of train sets are always operated
Life Cycle

Life cycle
- From design to deployment
  - Normally 3-5 years (if new development is necessary, 3-5 more years should be added)
  - Design and development are **led by JR companies** with the close cooperation of rolling stock suppliers.

Usage
- Normally less than 20 years - shorter than European rolling stock mainly because of
  - Fatigue
  - Following the changing customer demand and operational demand
  - Introducing new technology to improve performance and reduce maintenance cost

- Maintenance is done by JR companies
- Some series have been given major modification (renovation) to lengthen the life

Retirement
- Material can be recycled
Example of latest commercial train (westbound)

Series N700

- Formation: 14M2T
- Max Speed: 300km/h (186.4mph)
- Pass. Capacity: 1323
- Train Weight: Approx. 700t (loaded)
- Train length: 404.7m
- Power system: 25kV60Hz
  VVVF Control
  Induction Motor
- Signalling: Digital ATC
- Low noise structure
- Air suspension tilting
- Active suspension
- 10.7m aerodynamic nose for reduction of Tunnel Micro Pressure Wave

✓ Aimed at reducing travel time on Tokaido and Sanyo line by increasing speed at curve and high acceleration.
✓ Integration of high speed, quality riding comfort and environmental compatibility
✓ Commercial operation started in 2007.
Series E5 (being tested for commercial use)

- Aimed to reduce travel time on Tohoku line by increasing maximum speed.
- Research and development has been conducted by the operator (JR East) between 2002 and 2009. Tests had been conducted through dedicated experimental train sets.
- Commercial operation will start in 2011 at 300km/h.

<table>
<thead>
<tr>
<th>Formation</th>
<th>8M2T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Speed</td>
<td>320km/h (198.8mph)</td>
</tr>
<tr>
<td>Pass. Capacity</td>
<td>731</td>
</tr>
<tr>
<td>Train Weight</td>
<td>453t (loaded)</td>
</tr>
<tr>
<td>Train length</td>
<td>250m</td>
</tr>
<tr>
<td>Power system</td>
<td>25kV50Hz VVVF Control (IGBT) Induction Motor</td>
</tr>
<tr>
<td>Signalling</td>
<td>DS-ATC</td>
</tr>
<tr>
<td>Noise absorber</td>
<td></td>
</tr>
<tr>
<td>Active suspension</td>
<td></td>
</tr>
<tr>
<td>Air suspension tilting</td>
<td></td>
</tr>
<tr>
<td>15m aerodynamic nose for reduction of Tunnel Micro Pressure Wave</td>
<td></td>
</tr>
</tbody>
</table>
Remarks

- Operators (JR companies) have intended to fit rolling stock to the market needs and social and natural situations.

- Operators have led development and improvement of rolling stock with close cooperation with suppliers as the responsible body of safe, stable, reliable, comfort, and convenient transportation under many technical constraints.

- This ‘Market-in’ style strongly affects Shinkansen rolling stock design.

- Rolling stock is only a part of total high speed rail system. The rolling stock should be designed as a part of total optimum system. Of course, it must be compatible with the infrastructure.
Thank you very much for your attention.